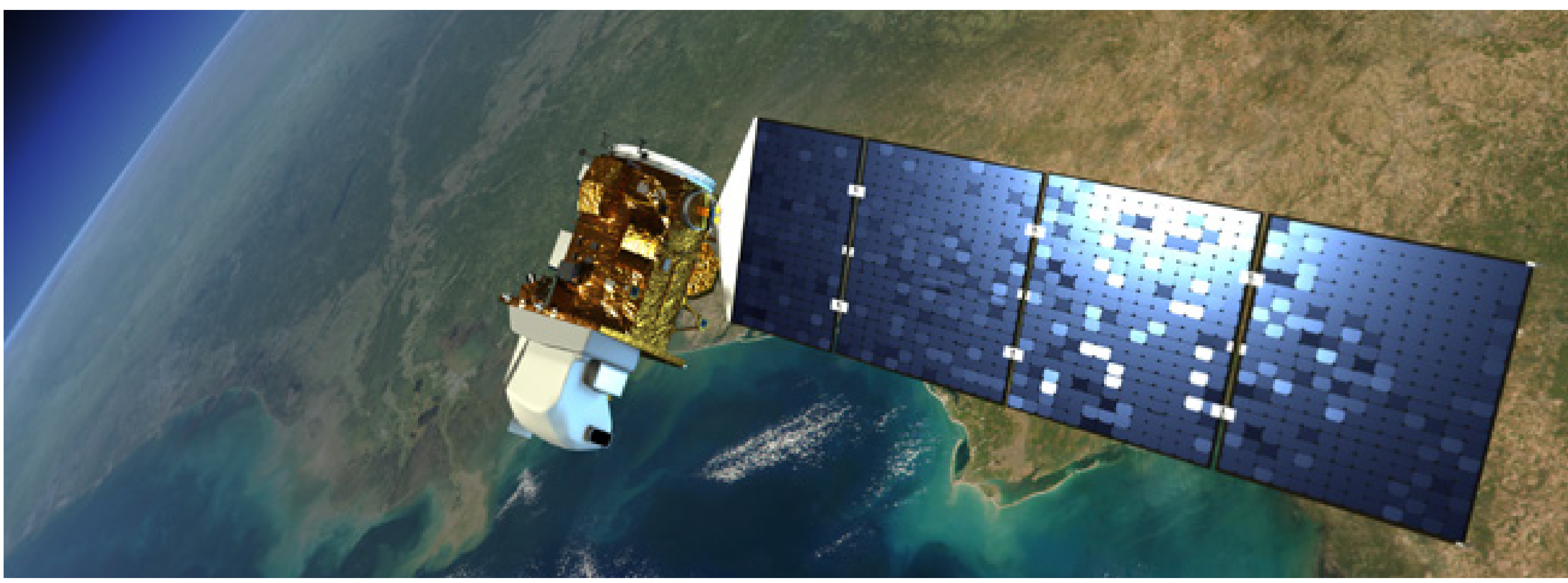
Learning and Teaching about Earth from Space with NASA/USGS Landsat Satellites



A Trainer's Toolbox

Produced by the NASA Landsat Education Team
2014

Train the Educator Toolbox:
Learning about Earth from Space with Landsat Satellites

Chapter I: "For the Trainer"

About the Toolbox
- What is the Toolbox?
- Purpose
- Goals and Objectives
- Landsat Scientists

Using the Toolbox
- How to Use the Toolbox to Give Teacher Professional Development Workshops
- Two Levels of Learning: Level 1 print-based; Level 2 computer-based
- Best Practices for Planning and Running a Workshop
- Workshop Goals (Levels 1 and 2)

Educational Context: Standards, Curricula, and Engaging Students
- Next Generation Science Standards Addressed
- Integrating Landsat with Existing Programs
- Engaging Learners

Materials and Tools
- Sample Agendas

Natural resource managers in California learned how to download and analyze Landsat data in 2012.

“For the Educator Participant”

Chapter II. Introduction to Landsat: A Special Way of Seeing the Earth

- Why We Look at Earth from Space
- What is Remote Sensing?
- What is Landsat?
- What People Do with Landsat
- How Landsat Images Are Made: “More than a Pretty Picture” (pdf)
- Quick Guide: More about the Imaging Process of Landsat Sensors

(Part 9, Appendix III contains a more in-depth treatment.)

Chapter III. Classroom Materials, Level I (print-based):

- Quantifying Changes in the Land over Time with Landsat Imagery

Chapter IV. Classroom Materials, Level 2 (computer-based):

- Part A. Finding and Downloading Landsat Data from USGS GloVIS Website
- Part B. Making Landsat Images in Adobe Photoshop
- Part C. Making Landsat Images Using ImageJ (no-cost software)
- Part D. Eyes in the Sky: Using ImageJ to Analyze Changes in the Land Over Time

Appendices

- Appendix I. Annotated List of Related Resources
- Appendix II. Background on our Changing Landscapes
  - *What is land cover change?*
  - *Why do people study land cover change?*
- Appendix III. More Background on Remote Sensing with Landsat
  - *What Are Satellites?*
  - *Gravity, Velocity and Orbits*
  - *Landsat Satellites and Their Instruments*
  - *Pixels, Bits, and Images*
  - *The Electromagnetic Spectrum*
  - *Spectral Bands*
  - *Making an Image with Landsat 7*
- Appendix IV. Glossary

Chapter I

About the Toolbox

❖ What is the Toolbox?

The Landsat Educator Training Toolbox is a resource for educators to train others about Landsat satellites, data, and images and the role of space-based observations of Earth in our rapidly changing, challenging world for career awareness.

Landsat is a national treasure. The federal government has funded a series of Landsat satellites to observe the Earth's continental lands since 1972 in a manner consistent through time and into the future, enabling us to better perceive and understand the places where we live.

Landsat gives us a new way of looking at the Earth. The data open our eyes to new ways of looking at our landscapes, and enables us to investigate change over time from the special perspective of space. Educators can put this new perspective into learners' hands using free images and free data, with free software that is relatively simple to learn and to use.

Studies with Landsat address the idea that technology often drives science (a National Science Education Standard). Because we have remote sensing technology and the space-based perspective, we have an opportunity to understand what these data are telling us. Geospatial technologies such as Landsat are effective tools for exploring any aspect of the Earth that has a spatial component. Educators who teach their learners about Landsat will be giving them a special skill that can enhance their ability to work in a multitude of professional disciplines.

Furthermore, all Landsat data are available to the public at no cost. See Part 4. How to Find and Download Your Own Landsat Data.

The U. S. Geological Survey provides Landsat data at least three Web sites:

Global Visualization Viewer
http://glovis.usgs.gov/

LandsatLook
http://landsatlook.usgs.gov

Earth Explorer
http://earthexplorer.usgs.gov

Two free software systems enable learners to analyze Landsat data:

ImageJ: http://rsbweb.nih.gov/ij/

MultiSpec™: http://cobweb.ecn.purdue.edu/~biehl/MultiSpec/

This Guide provides directions on how to use ImageJ to open Landsat images in different band combinations, and refers users to existing tutorials on analyzing Landsat data with both ImageJ and MultiSpec™.

❖ Purpose

The purpose of the Toolbox is to provide anyone who wishes to conduct educational workshops with all the necessary background information, classroom-ready resources, Landsat satellite images, and other tools needed to implement a professional development workshop on studying our planet's landscapes from the vantage point of space.

Participating educators can learn how to obtain and use Landsat satellite images to effectively meet interests and curricular needs in environmental, biological and Earth sciences. The Toolbox helps educator participants to achieve a level of comfort with interpreting satellite images and with making connections to real-life environmental issues related to land cover change over time, and for teaching concepts in science, mathematics, geography and social studies.

Educators at Piscataway National Park in Maryland learn to interpret Landsat images of their park.

❖ Goals and Objectives

<u>Goals</u>

- to provide educators with access to a valuable and important national asset for learning and teaching at no cost: the Landsat data and image archive
- to make resources for learning and teaching about federal remote sensing available for every middle and high school classroom teacher
- to give trainers the tools necessary to educate users in the downloading, analysis, and use of Landsat satellite images and data in classrooms and in parks, museums, and other informal learning centers
- to make explicit connections between remote sensing technology and national standards for classroom learning
- to enable greater student impact by achieving real-life relevancy for learners on local and community levels, with a global context
- to provide guidance on where one can learn more about remote sensing in education

Objectives

- to demonstrate how Landsat satellite images can be used to meet curricular and national standards requirements
- to inform educators about Landsat satellites, how their sensors work, and how Landsat images are created
- to provide educators with opportunities to discover how to interpret satellite images and use them to teach concepts about authentic land use issues in today's world
- to integrate the use of Landsat images in the teaching about the Earth environment and human impacts, climate change, social studies, geology, agriculture, and other disciplines

Community college instructors learn how to map a Landsat 30 m pixel.

The Landsat Science Team, February 2013

Landsat Science Teams provide technical and scientific input to USGS and NASA to help ensure the success of the Landsat program while providing science support on issues including data acquisition, product access and format, and science and applications opportunities. Each Team serves for a period of five years. The Team for 2012-2017 met near Vandenberg Air Force Base, CA at the time of the launch of Landsat 8 (Landsat Data Continuity Mission) in February 2013.

Using the Toolbox

❖ How to Use the Toolbox to Give Teacher Professional Development Workshops

Workshop goals and time available will dictate the agenda. Sample agendas for short, medium-, and long-duration workshops are included in this Guide and of course can be modified as needed. If the trainer wishes to teach participants how to use ImageJ or MultiSpec™ software for data analysis, at least 12 hours of training with follow up are recommended.

❖ Two Levels of Learning

The Toolbox provides two levels of learning and teaching about how to explore the world with Landsat data.

Learning Level 1 is image- and print-based and does not require learners' use of computers. The core of this learning level is the classroom activity, "Quantifying Changes in the Land Over Time." The URL for the online activity with all needed resources for teaching appear both below and in Part 7.
http://landsat.gsfc.nasa.gov/education/resources/Landsat_QuantifyChanges.pdf

Learning Level 2 is data-based and involves learners' analysis of Landsat data with ImageJ or MultiSpecTM software. The data and software are free.

KIT COMPONENTS
NEEDED FOR THE TWO LEARNING LEVELS

COMPONENT	LEVEL 1	LEVEL 2
Part 1: *About the Toolbox*	√	√
Part 2: *Using the Toolbox*	√	√
Part 3: *Materials and Tools*		√
Part 4: *Introduction to Landsat: A Different Way of Seeing the Earth*	√	√
Part 5: *Educational Context: Standards, Curricula, and Personal Connections*	√	√
Part 6: Classroom Materials, Level 1: *Quantifying Changes in the Land over Time*	√	
Part 7: Classroom Materials, Level 2: *Finding and Downloading Landsat Data from USGS GloVIS Website* *Making Landsat Images in Different Band Combinations Using ImageJ* *Making Landsat Images in Different Band Combinations Using Photoshop* *Using free ImageJ Software or MultiSpecTM to Analyze Landsat Data*		√

❖ Best Practices for Planning and Running a Workshop

For both Learning Levels:

- Read this document and become familiar with the concepts involved in remote sensing, satellites and their orbits, the imaging process, and interpretation of, and uses for, Landsat satellite images. Consider how you will deal with likely participant questions you may not be able to answer on your own. (Note "Contacts for Landsat Education" at the end of Part 1, above.)

  Appendix I provides an annotated list of more resources for learning and teaching about remote sensing.
- When designing the workshop agenda, be sure to allow participants plenty of time to absorb and use the new ideas, and to identify and share how the ideas can be integrated into the classroom curriculum.
- When recruiting participants for the workshop, be clear in your communications. Convey your target teacher grade level, prior knowledge required (if any), and what educators should expect to learn and be able to do as a result of participating in the workshop.
- Check the facilities where the workshop is being held to be sure the space is the right size and otherwise appropriate for a workshop.
- Make sure there are electrical outlets, power cords, extension cords, screens, projectors, software, and/or microphone(s) as needed.
- If you plan to use any kind of technology, test everything first. (Don't get stuck during the workshop!)
- Have all materials in hand well before the workshop. Consider copies of any printed or electronic files, pens/pencils, paper, binders with dividers, satellite images, etc.
- Become familiar with any satellite images to be used in the workshop. In preparation for using the classroom activity, "Quantifying Changes in the Land Over Time," take particular care to identify areas in each image pair that will best show change in the landscape over time.

For a Level 2 workshop:

- Practice downloading images from U.S. Geological Survey's GloVIS Website: http://glovis.usgs.gov/ . See Part 7 of this document, the section on "How to Find and Download Your Own Landsat Data."
- Become skilled at using ImageJ or MultiSpec™ software, and decide which of the two you will use.
- If you have only a two-hour workshop for users of ImageJ or MultiSpec™, be sure your participants know that before the workshop, they should do the following:

  √ *become comfortable identifying and downloading Landsat data from the USGS GloVIS Web site http://glovis.usgs.gov/*

  √ *become comfortable using ImageJ or MultiSpec™ for Landsat image analysis*

  √ *review the background material in Parts 9 and 10 of this document*

Running the Workshop

Generally the more actively involved learners are in their education, the greater the tendency for them to learn and truly understand. Educators participating in a professional development workshop are just like other learners in this regard. Involve participants in the design and implementation of their own professional development workshops as much as possible.

– Engage, question, and probe participants. Help them to make connections to their own teaching and to their daily lives outside their work.

– Use a pedagogical approach that engages participants actively in learning. One way this can be accomplished is by using a constructivist workshop design such as the 5 E's (engage, explore, explain, extend, evaluate). See Appendix III. "How to Construct Your Own Lessons Using "Understanding by Design."

– If possible, find out what participants already know about the ideas behind remote sensing – the electromagnetic spectrum, remote sensing, digital images, satellites, and sensors -- before the workshop or very early in it. Refer to and build on their knowledge as you move through the workshop.

– Limit the amount of time spent on covering each topic. Break big topics into smaller chunks.

– Make connections between concepts that may be new to participants and familiar real-life examples.

– To the extent you can, be sure participants have fully understood the concepts and grasped the skills in each section of the workshop before you move on. One way of doing this without putting participants on the spot is to pause and ask what misconceptions their learners might have about a given idea or skill, or ask what the educators might like help in teaching.

❖ Workshop Goals

Level 1: Print-based Learning

Goals

– Enable participants to understand and appreciate the value and feasibility of integrating satellite remote sensing into teaching in a classroom or museum environment

– Expose participants to the experience of investigating changes in the land over time using Landsat imagery

– Increase participants' level of comfort with interpreting satellite imagery

– Provide participants with a basic level of understanding on how the Landsat sensors work.

– Provide participants with resources for further learning and teaching about Landsat technology and data

Level 2: Computer-based Learning

Goals

(The first four and the last of these goals are the same as for two-hour agenda.)

– Enable participants to understand and appreciate the value and feasibility of integrating satellite remote sensing into teaching in a classroom or museum environment.

– Expose participants to the experience of investigating changes in the land over time using Landsat imagery.

– Increase participants' level of comfort with interpreting satellite imagery.

– Show how the Landsat sensor works, for educators' background understanding.

– Explain how Landsat is used to solve many problems for the benefit of society, and describe opportunities for careers using this and other geospatial technologies.

– Teach participants how to find and download their own Landsat scenes from this U.S. Geological Survey Web site http://glovis.usgs.gov

– Teach participants how to open Landsat scenes in different band combinations using ImageJ software.

– Describe and guide participants to other tutorials for analyzing Landsat data using ImageJ and MultiSpecTM software

– Provide participants with resources for further learning and teaching about Landsat technology and data.

Launch of Landsat 8 on February 11, 2013

Educational Context: Standards, Curricula and Personal Connections

❖ Next Generation Science Standards Addressed in This Kit

A Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts recommends science education in grades K-12 be built around three major dimensions:

– Scientific and Engineering Practices
– Crosscutting Concepts
– Core Ideas

Scientific and Engineering Practices Addressed in this Kit

Key to the vision expressed in the Framework is for students to learn disciplinary core ideas in the context of science and engineering practices.

Of the eight science and engineering practices identified by the Framework as essential for all students, the following are addressed in this Kit:

1. Asking questions
4. Analyzing and interpreting data
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining...and communicating information.

(From NGSS Appendix F – Science and Engineering Practices in the NGSS)

Crosscutting Concepts Addressed in this Kit

Crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas.

1. **Patterns**. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

Patterns figure prominently in the science and engineering practice of "Analyzing and Interpreting Data." Recognizing patterns is a large part of working with data. Students might look at geographical patterns on a map, plot data values on a chart or graph, or visually inspect the appearance of an organism or mineral.

7. **Stability and change**. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Stability and Change are the primary concerns of many, if not most scientific and engineering endeavors." Stability denotes a condition in which some aspects of a system are unchanging, at least at the scale of observation. Stability means that a small disturbance will fade away — that is, the system will stay in, or return to, the stable condition. Such stability can take different forms, with the simplest being a static equilibrium, such as a ladder leaning on a wall. By contrast, a system with steady inflows and outflows (i.e., constant conditions) is said to be in dynamic equilibrium. For example, a dam may be at a constant level with steady quantities of water coming in and out. . . . A repeating pattern of cyclic change—such as the moon orbiting Earth—can also be seen as a stable situation, even though it is clearly not static.

Disciplinary Core Ideas Addressed in this Kit

Middle School (6-8)

PS4.B: Electromagnetic Radiation

- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (MS-PS4-2)
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. (MS-PS4-2)
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. (MS-PS4-2)
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves. (MS-PS4-2)

MS-ESS3 Earth and Human Activity

MS-ESS3-3.	*Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.**
MS-ESS3-4.	*Construct an argument supported by evidence for how increases in human population and per-capital consumption of natural resources impact Earth's systems.*

Disc Core Idea: ESS3.C: Human Impacts on Earth Systems

- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. (MS-ESS3-3)
- Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3), (MS-ESS3-4)

High School (9-12)

PS4.A Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2), (HS-PS4-5)

PS4.B: Electromagnetic Radiation

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3)
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-4)
- Photoelectric materials emit electrons when they absorb light of a high-enough frequency. (HS-PS4-5)

PS4.C: Information Technologies and Instrumentation

- Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5)

HS-PS4-5.	*Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.**

HS-PS4 Waves and their Applications in Technologies for Information Transfer

HS-PS4-5.	*Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.**

PS4.A Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. (HS-PS4-1)
- Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2), (HS-PS4-5)

PS4.C: Information Technologies and Instrumentation

- Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5)

❖ Integrating Landsat with Existing Programs

Our ability to look at the Earth from space and to see change over time, particularly human impacts on the landscape, can serve as a framework for interdisciplinary studies in Earth Science, Social Studies, Language Arts, Chemistry, and/or Mathematics, as well as to address the role of technology in our lives.

Technology drives science in many ways. Because of Landsat and other satellites, we are asking questions about Earth that we could not have asked before, at least not with the expectation of effective answers! Exactly how many acres of land were deforested in a given region between 1990 and 2005? How far does a given air pollution event or dust storm travel from its source, across oceans to other continents? How extensive was sea ice around the North Pole during the last year, compared to the previous five years? How fast is the city of Las Vegas growing?

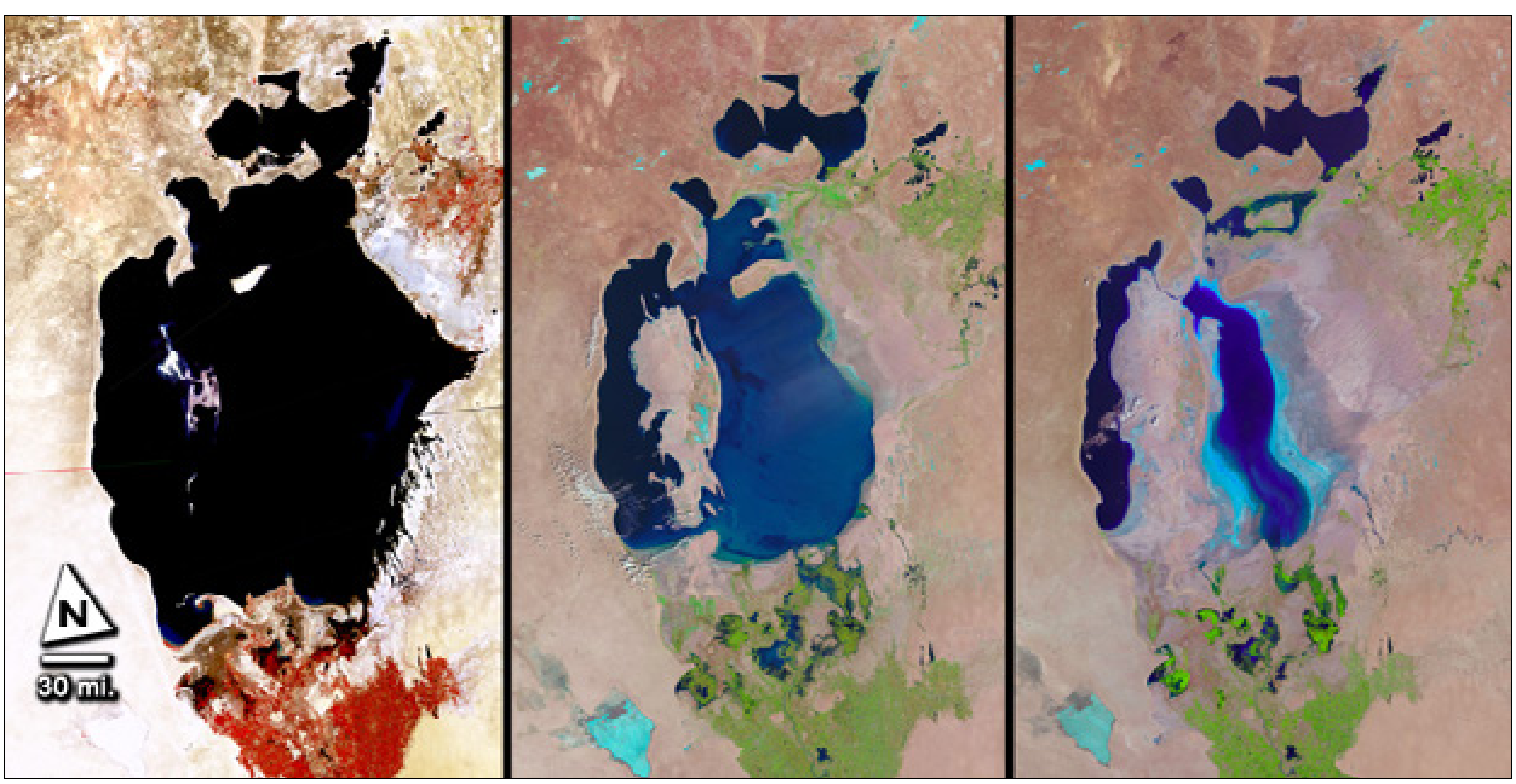
Most questions about Earth are best answered by integrating Landsat or other satellite data with other kinds of information such as maps, aerial photographs; historical information, census data, climate data, and so on. Questions with a spatial component are particularly well supported by Landsat.

Example: The Disappearing Aral Sea

When teaching about early civilizations, educators can help learners use Landsat images to investigate the disappearing Aral Sea. Located in Uzbekistan and Kazakhstan and once the fourth largest lake on Earth, the Aral Sea has shrunk dramatically over the past few decades. The primary rivers that once fed the Sea have been diverted for cotton farming and other agriculture. The southern part of the Sea once moderated the region's continental climate, which was warmer and had more precipitation than today, and which supported a productive fishing industry.

The river diversion process was begun in the 1960s. Landsat satellite imagery taken in 1989 shows that by then the northern and southern halves of the sea had become virtually separated. The drying of the Sea's southern section exposed its salty seabed. Dust storms increased, spreading the salty soil into agricultural lands. As the agricultural lands became contaminated by salt, farmers tried to combat the process by flushing the soil with huge volumes of water. Water that made its way back into the Sea was not only very salty but also polluted by pesticides and fertilizers.

The Sea continued to disappear, and by 2003 (Landsat image on the right, below) there was little water remaining. Educators can ask learners to consider and investigate these questions: How does the loss of the Aral Sea affect the economic well-being, culture, and physical health of the people who depended on it? Where do they get fresh water now that the Sea is almost completely dry? How much water has been pumped out of the rivers that feed this lake? How can we find out?



Landsat images of the Aral Sea in 1977, 1998 and 2010 illustrate the dramatic decline of one of the most important freshwater resources in Uzbekistan and Kazakhstan. Image courtesy of NASA GSFC archives.

Pairs of Landsat images such as those of the Aral Sea can be used for educators and learners to pursue investigations of many kinds for locations around the globe.

See also the section of this Guide. Finding and Downloading Landsat Data from USGS GloVIS Website.

Following are ideas for some investigations learners can do using Landsat.

How does the growth of a city affect its water quality?

(See the Toolbox activity, "Quantifying Changes in the Land Over Time")

√ **Social Studies, Mathematics, Chemistry**

Reduction in pervious (permeable) surfaces affects water flow. Water that falls on impervious surfaces such as streets, parking lots, and buildings does not percolate into the soil and the substrate below it. The passage of water through such areas can cleanse it of some pollutants. So when the land is covered over with impervious surfaces, water that falls on it carries more urban pollution into adjacent streams, rivers, lakes, and bays.

Is snow in the California mountains melting earlier in spring than it did 10 or 20 years ago? If so, how is that change affecting the availability of water for agriculture?

√ **Biology, Natural Resources**

Early snowmelt changes the time of year when water is available to both domestic (agricultural) and wild plants and animals living at elevations below.

What are the environmental and economic consequences of wildfires?

√ **Biology, Mathematics**

Wildfires are natural processes that alter the faces of landscapes. Small fires are usually beneficial. Big fires will ruin a forest for timber, and they can make forests uninhabitable for most wildlife for years. Landsat can help to track the extent and severity of a fire, to show where mitigation efforts should take place, and to monitor the re-growth of vegetation after the fire.

How fast are the world's mountain glaciers melting?

√ **Climate Change**

Learners can measure the extent of specific glaciers in Landsat scenes a decade or more apart, to determine the sizes of areas that may have thawed over that period of time.

What is the extent of a particular flood?

√ **Social Studies/Geography**

Using Landsat the boundaries and extent of a given flood event can be measured regardless of dangerous conditions and distances on the ground. In fact insurance companies use remote sensing to help discover fraudulent insurance claims due to flooding.

Are our croplands stressed from drought or disease?

√ **Agriculture, Mathematics**

Landsat can help to quantify the health of crops by providing data on how much photosynthetic activity is taking place in a given cropland. Helping farmers to pinpoint areas of stress can support targeted intervention and thereby even help to boost crop yield.

Where is the best habitat for a population of mountain sheep or other species in a given natural area?

√ **Biology, Ecology**

Kinds of ecosystems and their productivity can be assessed using Landsat, and that data can be integrated with knowledge about the biological requirements of a given species.

How fast is deforestation taking place in a specific region of the world?

√ **Ecology, Geography**

Landsat is excellent for observing deforestation over time. How is deforested land being used? What effects does this land use change have on populations of people and of wildlife?

Are deserts spreading in certain regions of the world?

√ **Social Studies/ Geography, Biology**

Landsat can show large landscape-scale changes in the boundaries of ecosystems such as deserts. Ecosystem boundary studies can be linked to investigations of changes in health, well-being, and livelihoods of specific human populations.

Geomorphology

√ **Geography**

What do particular landforms look like from space? Landforms such as river deltas, coastlines, and volcanoes can be appreciated and examined readily in Landsat images. Such study can help us to recognize similar features on other planets.

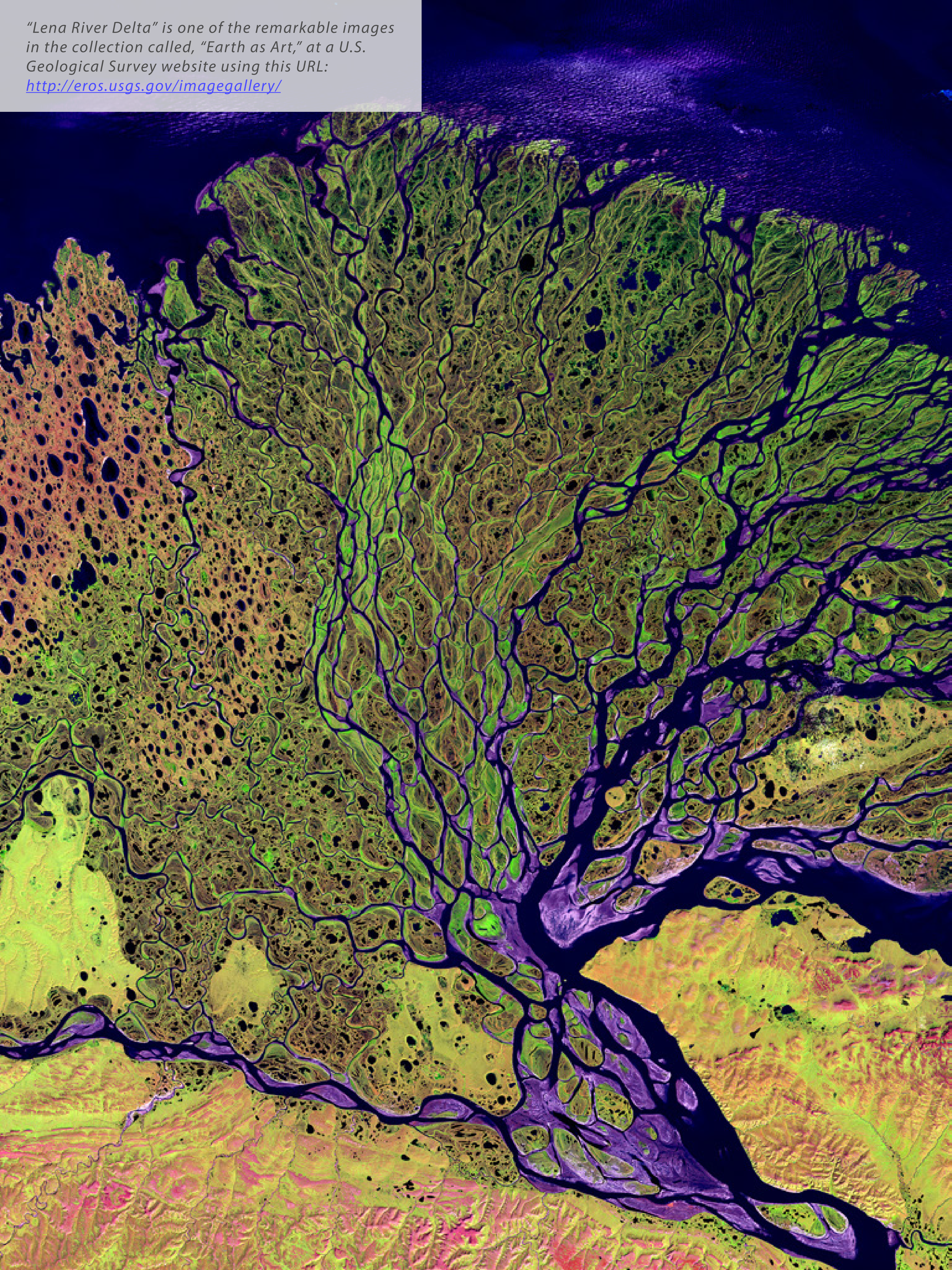
Earth as Art

URL: https://eros.usgs.gov/imagegallery/earth-art

√ **Art, Language Arts**

The visual richness of the Earth, as seen in this remarkable collection of satellite images, can be employed to address standards in the Arts for the purpose of creating artwork from any medium, and for Language Arts writing projects such as poetry and short stories. Subjects include landforms such as river deltas and volcanoes.

"Lena River Delta" is one of the remarkable images in the collection called, "Earth as Art," at a U.S. Geological Survey website using this URL: [*http://eros.usgs.gov/imagegallery/*](http://eros.usgs.gov/imagegallery/)



❖ Engaging Learners

Making Personal Connections

Seeing their own homes, schools, and communities in a Landsat image can give learners a new sense of connection and appreciation for where they live in relationship to other places. This experience can make it easier for them to see relationships between their locations and places they may have heard about but never have visited.

Educators can ask learners to investigate a local issue that matters to them, and then to "scale up" and explore the issue regionally or globally. Learners can become aware of changes that are good, and ones that are not so good, for themselves, their communities, and the global environment.

Means of engaging learners' interest can include holding a discussion on how learners use Google maps (with satellite images). Landsat forms the basis for Google maps. *(When higher resolution imagery is available, the Google system switches to it automatically, without overtlly indicating a change to the user.)*

Resources for Engagement

Below is an annotated list of resources that can help educators to engage the interest and participation of learners.

Earth as Art (also noted above)

http://eros.usgs.gov/imagegallery/

A selection of dozens of remote sensing images selected for their aesthetic qualities. Subjects include landforms such as river deltas and volcanoes.

Geospatial Revolution

http://geospatialrevolution.psu.edu

This video series by Penn State University shows how geospatial technology has become integrated into our daily lives and explains its role and importance for multiple societal benefits. The video makes a case for young people to consider careers that use geospatial technology.

A Landsat Flyby

http://svs.gsfc.nasa.gov/vis/a010000/a010500/a010513/

A short video about ways people can use Landsat.

Urban Sprawl: Phoenix (American Museum of Natural History)

http://www.amnh.org/explore/science-bulletins/%28watch%29/bio/visualizations/urban-sprawl-phoenix

Time sequence / movie about how since the mid-1980's, the city's population density has increased as people continue to move to the region even as the urban area's boundaries have grown more slowly. This trend is by necessity, since the water supply cannot feed an ever-expanding metropolitan area.

EarthNow! Landsat Image Viewer

http://earthnow.usgs.gov/

The site offers a continuously unrolling sheet of views of North America from orbit. An inset window in the upper right corner tells you where you are looking.

Materials and Tools

Level 1 Materials and Tools (no participant computers)

– Computer, projector, and screen for computer-based training media presentations
– (Optional) Laser pointer

Level 2 Materials and Tools (at least one computer for two participants)

– Computer, projector and screen for computer-based training media presentations
– Computer for each participant, with the following software
  - o Word Processing software
  - o Image software such as iPhoto, Photoshop, Corel, or other
  - o Video software such as Flash, Windows Media, Player, Quick-time, Real Player, or other
  - o ImageJ or MultiSpec™ - both available for download for both Mac and PC at no charge:

    ImageJ: http://rsbweb.nih.gov/ij/download.html

    MultiSpec™: http://cobweb.ecn.purdue.edu/~biehl/MultiSpec/

– (Optional) Laser pointer
– Landsat scenes (data) for areas of interest to participants

❖ Sample Agendas

Agenda for 2.0 hours

I. Introduce the workshop: goals, expectations; staff, participants (15 min.)

- *Make entries on pre-assessment chart*
- *Share contact Info*
- *Review agenda and notebook contents*
- *Goals and Objectives*
- *Intro to subject matter: Studying Earth from Space*

II. Engage and Explore (15 min.)

- *Explore Landsat images:*
- *Landforms Quiz*
- *Landsat videos*

III. Explain (1 hr.)

- *How Landsat Images Are Made (PPT)*
- *Think and Share*

  BREAK

- *Getting to Know Your Landsat Image (GLOBE Program)*
- *Quantifying Land Cover Change with Landsat*

- *Think and Share*

BREAK

IV. Elaborate, Evaluate (30 min)

- *So What? – Uses for Landsat Data and Images*
- *Integrating Landsat into your curriculum (National Standards and Landsat)*
- *Learn about more resources for learning and teaching with land remote sensing*
- *Think and Share*
- *Complete post-assessment chart*
- *Feedback for workshop staff*

Agenda for 4.5 hours

I. Introduce the workshop: goals, expectations; staff, participants (15 min.)

- *Make entries onto pre-assessment chart*
- *Share contact Information*
- *Agenda and Notebook Contents*
- *Goals and Objectives*
- *Intro to subject matter: Studying Earth from Space*

II. Engage and Explore (15 min.)

- *Explore Landsat Images:*
- *Landforms Quiz*
- *Landsat Movies*

III. Explain (1 hr.)

- *How Landsat Images Are Made (PPT)*
- *Think and Share*

BREAK

- *Getting to Know Your Landsat Image (GLOBE Program)*
- *Quantifying Land Cover Change with Landsat*
- *Think and Share*

BREAK

IV. Elaborate, Evaluate (2 hrs. 30 min.)

- *Download your own Landsat scenes from USGS website, GloVIS (30 min.)*
- *Open scenes in different band combinations using ImageJ (15 min.)*
- *Introductory use of ImageJ (45 min.)*
- *So What? – Uses for Landsat Data and Images (15 min.)*
- *Integrate Landsat into your curriculum (National Standards and Landsat) (15 min.)*
- *Learn about more resources for learning and teaching with land remote sensing (15 min)*
- *Complete post-assessment chart (15 min.)*
- *Feedback for workshop staff*

Chapter II

❖ Why We Look at Earth from Space

Earth science has always been part of NASA's mandate, but now Earth observing programs are much more extensive and important for society's well-being than some might have predicted when NASA began its work. **What we have seen of Earth from space is so compelling that we must look again and again, and again.** We are driven to develop new technologies to look better, and deeper. Current questions, cutting edge technology, and knowledge lead to greater understanding, more questions, and new technology. NASA technology drives science in many ways.

The incredible power of these space-based observations provides us with new tools to help address climate change, agricultural efficiency, disaster management, homeland security, and urbanization, and other issues of importance to human life. Earth is an extremely complex, dynamic system which we do not yet fully understand.

NASA pursues five major research questions in Earth systems science:

- How is the global Earth system changing?
- What are the primary causes of change in the Earth System?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of change in the Earth systems for human civilization?
- How can we predict future changes in the Earth system?

To learn more about NASA Earth science, visit:

http://nasascience.nasa.gov/earth-science

http://earthobservatory.nasa.gov

❖ What is remote sensing?

"Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information." (Canada Centre for Remote Sensing, Tutorial: Fundamentals of Remote Sensing, accessed online May 25, 2010) Sensors can be flown on satellites, airplanes, or balloons.

For more about remote sensing, visit the Earth Observatory feature article, Remote Sensing, at this URL: http://earthobservatory.nasa.gov/Features/RemoteSensing/

❖ What Is Landsat?

The Landsat Program is a series of Earth-observing satellite missions now jointly managed by NASA and the U.S. Geological Survey. Since 1972, Landsat satellites have taken specialized digital datasets (scenes) of Earth's continents and surrounding coastal regions, enabling people to study many aspects of our planet and to evaluate the dynamic changes caused by both natural processes and human practices.

Landsat provides essential maps for understanding and caring for the places we live and work. The duration, quality, and consistency of Landsat observations enable professional and student investigations of local, regional, and global changes in the land and their communities over time. Pixel by pixel, Landsat has been consistently gathering data about our planet, recording the entire global land surface, every season, every year. The science and technology of remote sensing have matured with the Landsat Program.

Landsat 5 was in orbit from 1984 until 2012. Landsat 7 launched in 1999, and Landsat 8 early in 2013.

❖ What People Do with Landsat

Landsat provides the longest and most complete record on the state of the global land surface in existence. People use Landsat data for a multitude of purposes.

Agriculture

- Track crop productivity and predict yield
- Evaluate crop stress
- Monitor crop health
- Quantify evapo-transpiration from individual fields and rangelands

Carbon and Climate

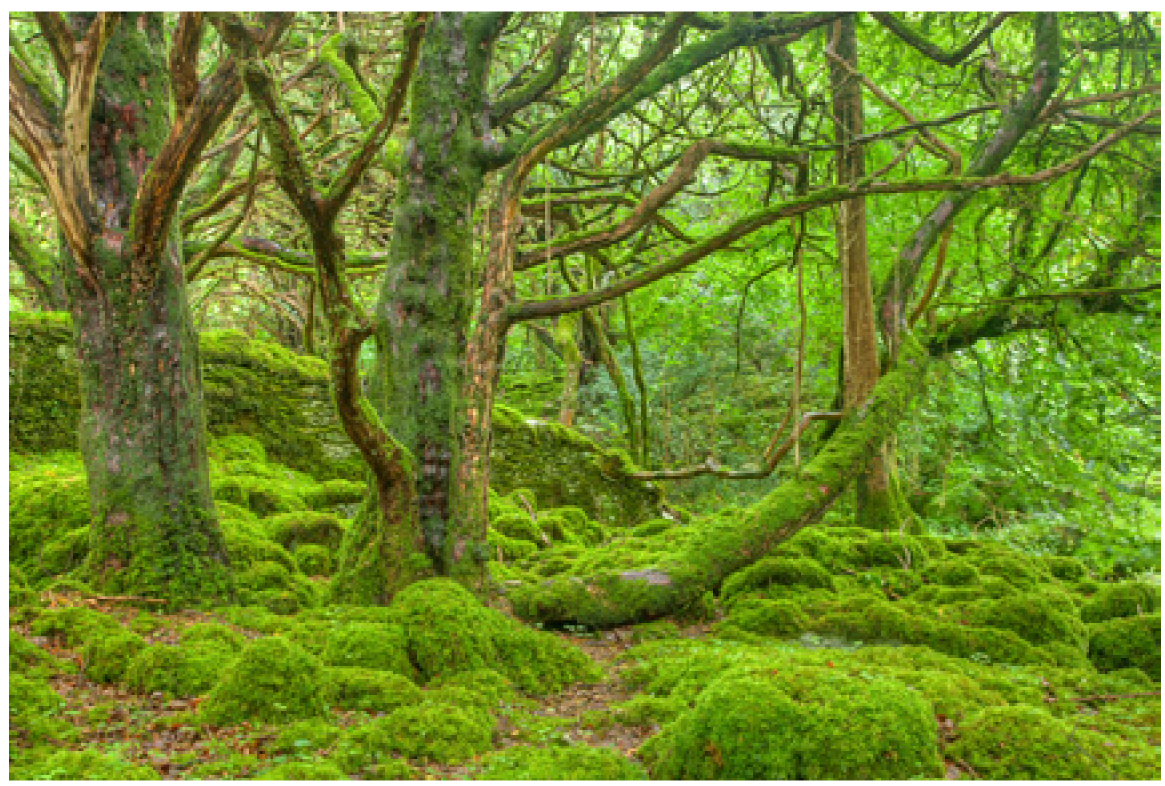
- Monitor Earth's carbon on land
- Understand how land use affects climate, such as through the influence of cities
- Track the impact of climate change, such as new insect infestations in forests
- Adapt to climate change, such as mapping human settlements and infrastructure susceptible to climate-driven hazards.

Disasters

- Measure the extent of damage from floods, tornadoes, and droughts
- Map pathways of volcanic eruptions to provide risk assessment and advance warning
- Quantify the severity of fire damage for ecological mitigation

Ecosystems and Biodiversity

- Map Ecosystems
- Quantify the rate and extent of forest disturbance and regrowth
- Track species distributions
- Assess the effectiveness of ecosystem restoration projects



Killarney Forest - Image Credit: Nicolas Raymond

Fire

- Assess the severity and extent of damage
- Improve safety and preventing further damage to life, property, and natural resources
- Estimate how much pollution burning releases into the air
- Monitor burn areas and regrowth
- Assess susceptibility to wildfire

Forest Management

- Conduct forest assessments for timber inventory
- Predict tree growth and product yield
- Assess forest health
- Map insect and disease damage and future risk
- Map deforestation and reforestation
- Map forest disturbance at regional and continental scales

Human Health

– Map geographic areas where some disease outbreaks (such as Hanta virus, malaria, and Rift valley fever) may occur

– Protect food sources

– Conduct cancer research

Urban Growth

– Monitor urban sprawl and land use efficiency

– Measure impervious surface area

– Observe heat island effects

– Link urban growth and rainfall pattern change

Water

– Locate water resources

– Assess water pollution

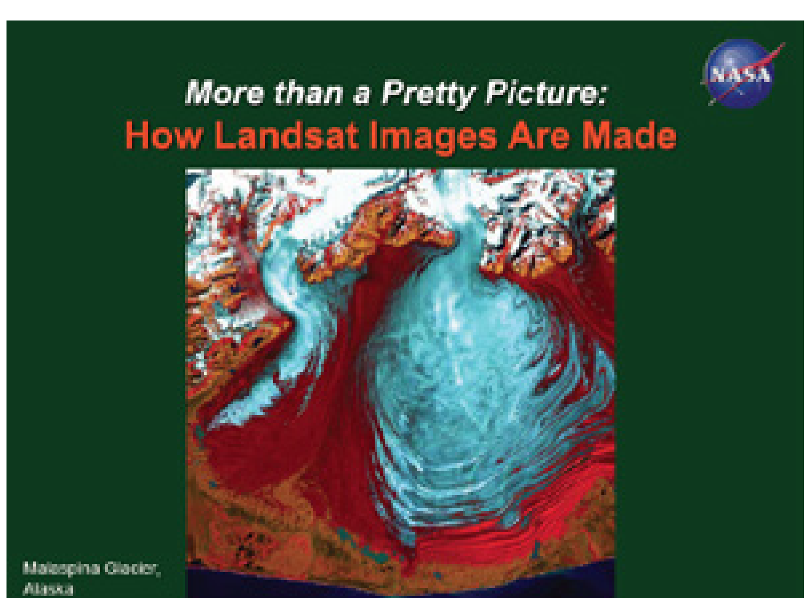
– Manage watersheds

– Allocate water resources

❖ How Landsat Images Are Made: More than a Pretty Picture (pdf)

“More than a Pretty Picture” conveys how Landsat uses reflected light to enable people to identify and quantify what covers the land surface around the globe. Whether or not educators intend to teach this material, we strongly recommend both educators and their students review it to understand the nature and importance of Landsat data.

How Landsat Images Are Made: More than a Pretty Picture can be viewed and downloaded at this URL: http://landsat.gsfc.nasa.gov/wp-content/uploads/2014/09/Landsat_MoreThanPrettyPicture.pdf



❖ Quick Guide: More about The Imaging Process of Landsat Sensors

Landsat satellites carry sensors that measure specific wavelengths of energy reflected from the surface of the Earth. The wavelength ranges are in the visible red, green, and blue, and in infrared wavelengths.

There is a three-step process to getting a finished image. The first step is the sensor's observation of the values of captured wavelengths and recording the amount of reflected light on a scale of 0-255 (Landsat 5 & 7) or 0-4095 (for Landsat 8) for each 30m x 30 m area on the Earth's surface. The second step is to assign a visible color to the numerical (grayscale) data. The third step is to create a composite from the three bands chosen to create an image.

Explanations of this process appear in the presentation, How Landsat Images Are Made: *More than a Pretty Picture* (mentioned above)

This Quick Guide summarizes basic concepts about –

- the orbits of Landsat satellites
- the electromagnetic spectrum and its use by sensors onboard the satellites
- spatial resolution
- spectral resolution
- interpreting the data

- The path followed by a satellite is referred to as its orbit. Landsat satellites orbit the Earth from the north pole to the south pole and around the globe continually as the Earth turns below them, in what is known as a polar orbit. They pass over the same part of the Earth at roughly the same local time each day, following the sunlight (in a Sun-synchronous obit). Having the Earth's surface lit by the Sun is necessary in order for the Landsat sensors to do their work of detecting reflected radiant energy.

- The satellites' orbit altitude is 705 km (438 miles) at the Equator. The spacecraft complete just over 14 orbits per day, covering the entire Earth between 81 degrees north and south latitude every 16 days. With both Landsat 7 and 8 in orbit, each location on the surface is visited every eight days.

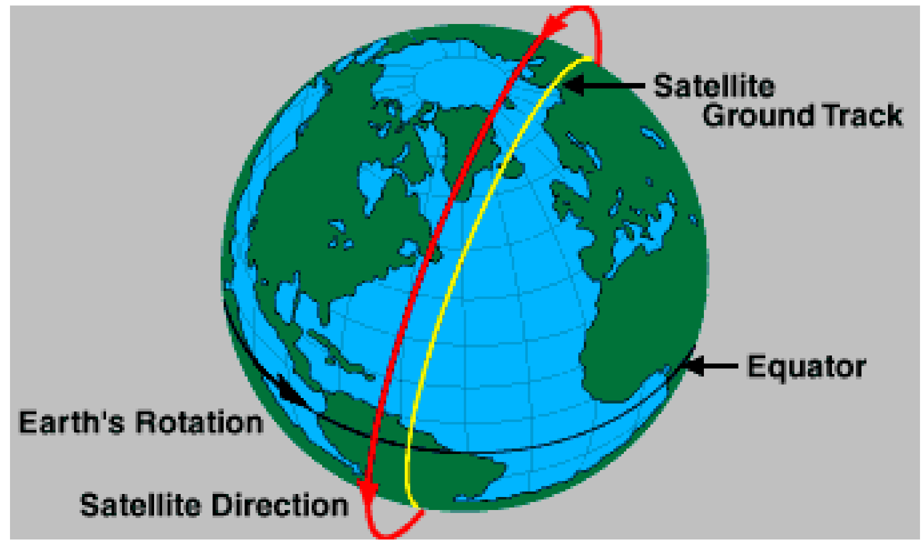
- The repeating nature of Landsat overpasses does not mean that every possible scene is collected. Costs of data archiving and storage make this impossible. Scenes are collected according to a carefully planned schedule that takes multiple factors into account. For example, Landsat does not see through clouds, so if a given area is too cloudy, the sensor will not collect that scene. Landsat engineers do their best to collect scenes of every part of North America, every season of every year.

- Landsat observes the Earth in paths (swaths) that are chunked into scenes. Each scene is 185 km (across-track) by 180 km (along the swath, or along-track).

Related Resource

NASA Movie about Landsat Orbit: *Landsat Orbit Swath*, at:

http://svs.gsfc.nasa.gov/vis/a010000/a011400/a011481/index.html

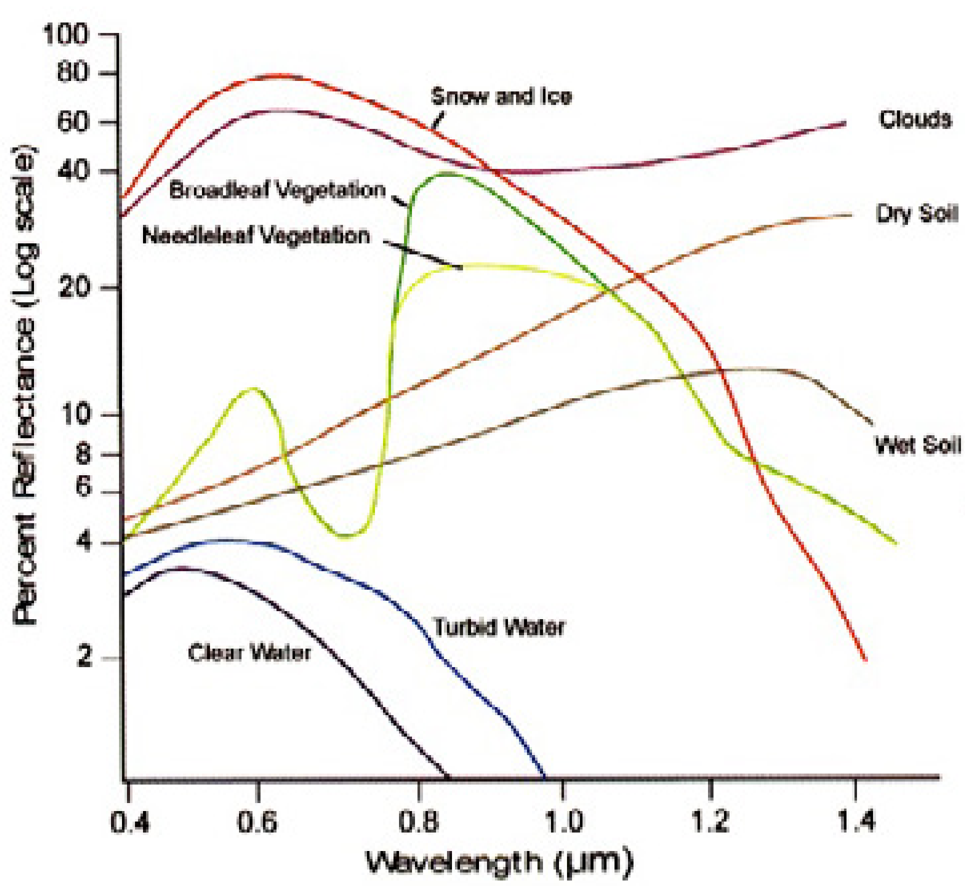


Landsat's orbit is near-polar and synchronized with sunlight. In other words the satellite observes the same locations on the Earth's surface at the same time everyday, so the angle of sunlight is consistent from one observation date to another. Credit: National University of Singapore, Center for Remote Imaging, Processing, and Analyzing

The Electromagnetic Spectrum

For an excellent introduction to the electromagnetic spectrum, download and show the video series, "Tour of the Electromagnetic Spectrum," at this URL: http://missionscience.nasa.gov/nasascience/ems_full_video.html

– ***Core Concept:*** For any given material, the amount of reflected and emitted radiation varies by wavelength. In other words, a specific material reflects each different wavelength at a different intensity (to a different degree), and does so consistently. We can learn to recognize that material's "spectral signature."



Differences in spectral signatures appear in this illustration. For example, snow and ice reflect strongly in wavelengths between 0.5 and 0.7 nm. They absorb strongly in wavelengths between 1.2 and 1.4 nm. Clear water reflects wavelengths of 0.45 nm, and it strongly absorbs wavelengths of 0.8 nm. Clouds reflect strongly in all wavelengths depicted here.

- Sensors on Landsat satellites detect specific ranges of wavelengths of the electromagnetic spectrum that are reflected from Earth's surface. In Landsat 5 & 7 data, the intensity of the reflected wavelengths is measured on a scale of 0 to 255 for 256 measurable levels of intensity. In Landsat 8 data, it is measured on a scale of 0 to 4,095 for 4,096 measurable levels of intensity. With Landsat 8 we can see many more shades of the light we are measuring, and we can study greater nuance in our scenes of interest

- Specific wavelength ranges used by Landsat sensors are known as bands. Landsat 7's sensor detects seven specific bands of electromagnetic radiation.

Landsat 8's two sensors together detect eleven bands of electromagnetic radiation, and the band numbers are a little different.

Landsat 7			**Landsat 8**	
			Coastal blue	Band 1
Band 1	Blue		Blue	Band 2
Band 2	Green		Green	Band 3
Band 3	Red		Red	Band 4
Band 4	Near infrared		Near infrared (IR)	Band 5
Band 5	Short-wave infrared-1		Shortwave IR-1	Band 6
Band 7	Short-wave infrared-2		Shortwave IR-2	Band 7
Band 8	Panchromatic		Panchromatic	Band 8
			Cirrus	Band 9
Band 6			Longwave IR-1	Band 10
			Longwave IR-2	Band 11

For an illustrated description of Landsat 8 bands by Charlie Lloyd, MapBox, go to: http://landsat.gsfc.nasa.gov/?page_id=5377

Spatial Resolution

- The smallest discrete component of a Landsat image is called a picture element or pixel. The greater the number of pixels per area on the ground that is observed, the higher the spatial resolution. And the smaller the area represented by each pixel, the higher the spatial resolution. In other words, a pixel size of 30 m x 30 m provides higher resolution than a pixel size of 250 m x 250 m.

- The spatial resolution of most Landsat 7 and 8 sensor bands is 30 m. (Both satellites have thermal bands with coarser resolution.) This means that each pixel in a Landsat image represents an area on Earth's surface 30 m by 30 m.

- Landsat is considered to have moderate resolution, that is, neither too coarse or too detailed for studying the landscape. At Landsat's spatial resolution, we can clearly distinguish the impacts of human activities: how how human activities affect and are affected by the land.

Interpreting the Data

- How to Interpret a Satellite Image: Five Tips and Strategies
  http://earthobservatory.nasa.gov/Features/ColorImage/?src=features-recent

  Excerpt from page 1:

  Satellite images are like maps: they are full of useful and interesting information, provided you have a key. They can show us how much a city has changed, how well our crops are growing, where a fire is burning, or when a storm is coming. To unlock the rich information in a satellite image, you need to:

  - Look for a scale
  - Look for patterns, shapes, and textures
  - Define the colors (including shadows)
  - Find north
  - Consider your prior knowledge

- Reminders:

  For Landsat 5 or 7, the intensity of the reflected light is measured on a scale of 0 to 255. For Landsat 8, the intensity of reflected light is measured on a scale of 0 to 4095. In a Landsat image, pixels with values of 0 indicate that no radiant energy in that wavelength range or band is being reflected. It is all being absorbed by the target. Pixels with values of 255 (Landsat 5 or 7) or 4095 (Landsat 8) indicate that all radiant energy in that wavelength range is being reflected, and none is being absorbed. By far most pixel values fall somewhere between 0 and 255 / 0 and 4095.

- Landsat data appear first in shades of gray. The grayscale image can be converted to visible colors using computer software programs. The software enables people to choose what color they want to use for each band of data they want to see.

Chapter III

Classroom Materials, Level 1 (print-based):

❖ Quantifying Changes in the Land over Time with Landsat Imagery

Click on the hotlink in the below, or copy and paste the URL into your browser:
http://landsat.gsfc.nasa.gov/education/resources/Landsat_QuantifyChanges.pdf

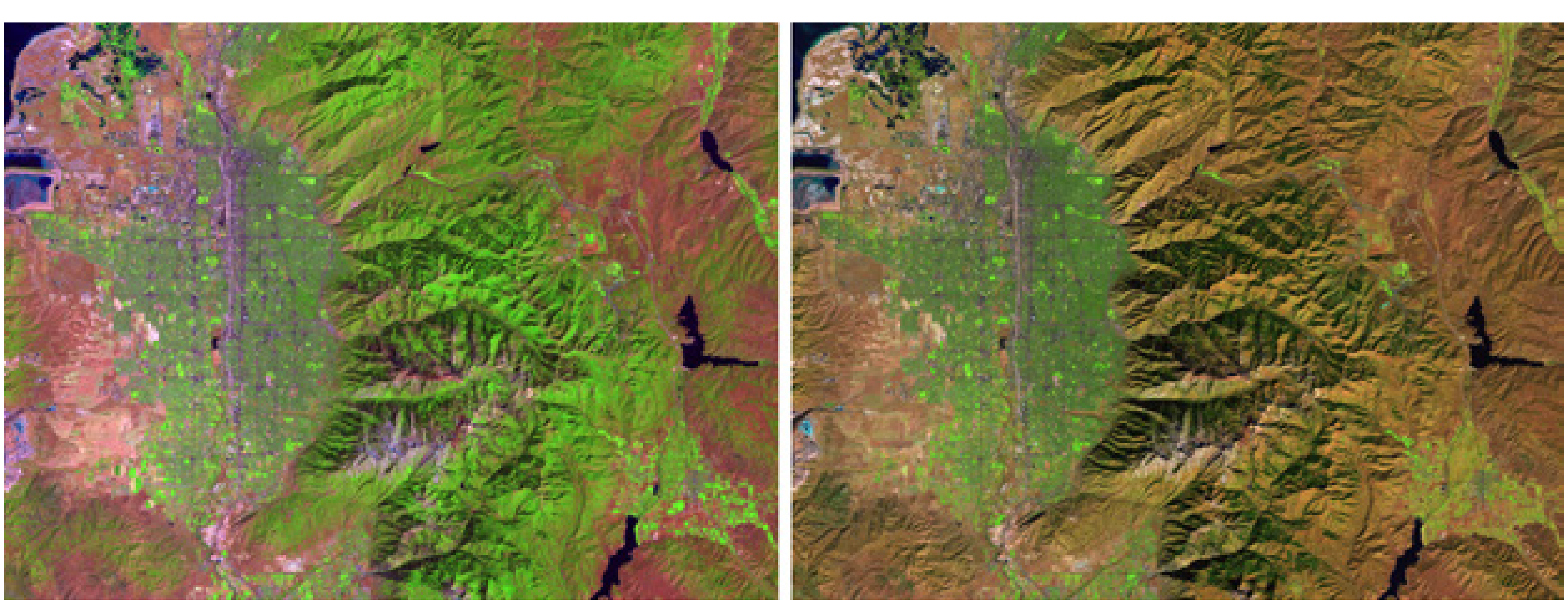
Identify and download two Landsat scenes of the same place, 10-15 years apart.

OR find an existing "change pair" of images at one of the websites listed below under, "Where to Find Pairs of Images for the activity, *Quantifying Changes in the Land Over Time*," p. 36 of this Guide.

To download your own "change pair," use the tutorial below, FInding and Downloading Landsat Data from the U.S. Geological Survey's Global Visualization Viewer Website.

Note: Looking at change over time can involve looking at seasonal change. When you select the dates of the scenes to download, get scenes with time of the year as close together as possible. In other words, if the earlier scene selected is from August 15, do your best to find a scene 10-15 years later as close as possible to August 15.

The importance of comparing pairs of images from the time of year is illustrated in the figure below. The image at left was acquired over Salt Lake City on August 14, 1999, and the image at right was acquired about two months later on October 17, 1999. Both images use Landsat 7 band combination 5,4,2 – two infrared bands and the visible green band. The dramatic color changes from August to October in the mountains to the east of the city indicate that the growing season has finished there, while there is still some vegetation growing in the valley. Someone comparing these images without knowing the seasons were different might think a great deal of change in land use had taken place when in fact it had not.



These Landsat views of Salt Lake City, UT were recorded during different seasons. The image at left shows more vegetative growth, particularly in the mountains east of the city.

Three-page Summary of the Activity, "Quantifying Changes in the Land Over Time"

Overview

Students learn to interpret satellite images of the Earth's land surfaces. They make a map of land cover types (urban areas, vegetated areas, water bodies) and a map of changes in the land over time. They quantify the changes in terms of percent of the area that has changed. They make maps of future land cover given the same kind and rate of change, and consider the consequences for people and ecosystems.

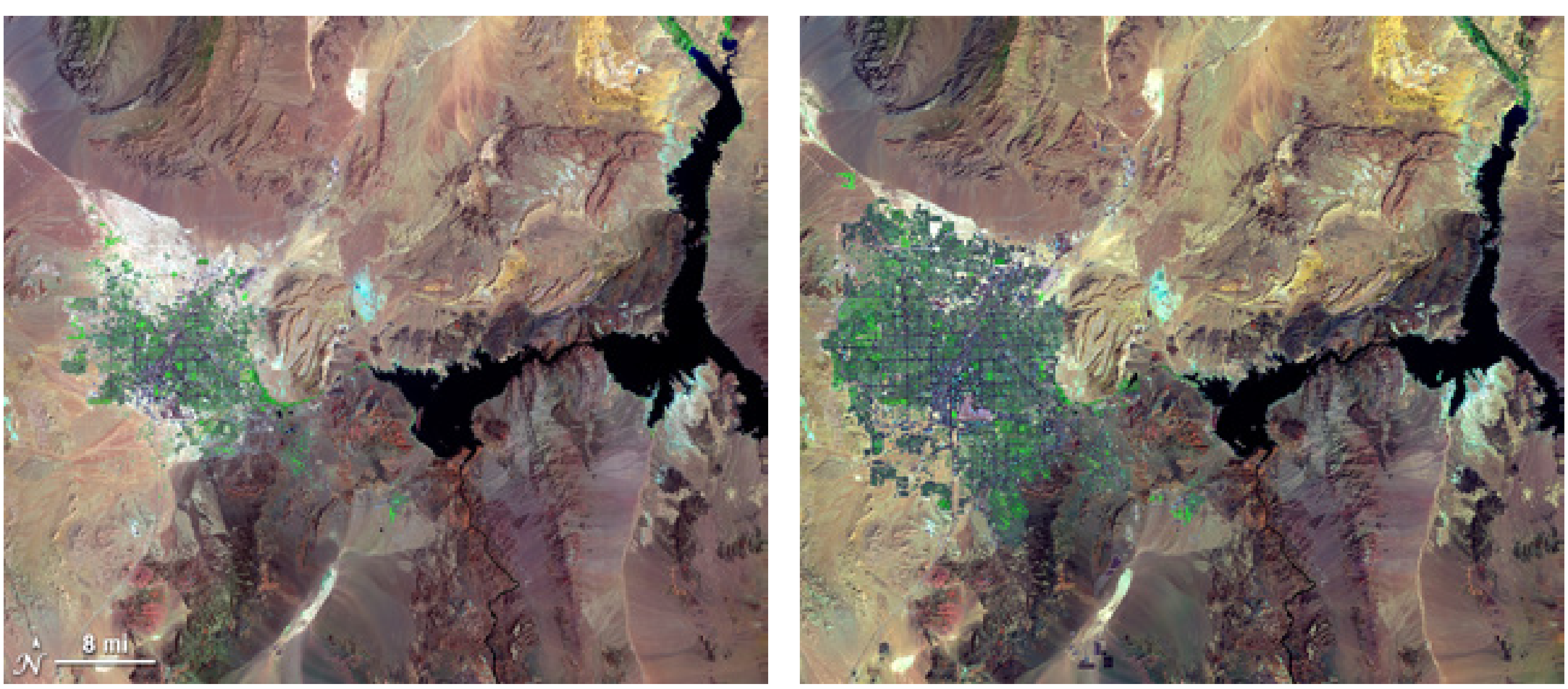
Time Required

Two 45-minute periods

Objectives

As a result of going through this activity, students will:

- Be able to identify some major land cover types in a land remote sensing image
- Make maps of land cover at a regional (landscape) scale
- Quantify land cover change over time
- Predict ways and directions that an urban area might grow
- Realize that land cover / land use in our country is changing in significant ways, and that this has implications for management of the natural resources we depend on
- Begin to appreciate the value of planning in urban growth to protect natural resources



False color Landsat images of Las Vegas, NV, in 1991 (left) and 2000 (right) include reflected infrared wavelengths of light. This particular combination of wavelengths clearly distinguishes urban from non-urban areas, and one can observe the growth of the city over time.

Activity Steps at a Glance

Engage

Step 1. Review movies about the roles of satellites in our lives and about the growth of an urban area, Phoenix, AZ *(5 min.)*

Step 2. For homework, read the one-page section of this activity, "Background on Land Cover Change" and the article, "Looking for Lawns."

Explore

Step 3. Do the GLOBE Program activity, Getting to Know Your Satellite Imagery, attached at the end of the Guide for Students. *(20 min.)*

Step 4. Visually explore and become familiar with the 1990 Landsat image, list any identifiable features and land cover types. *(10 min.)*

Step 5. Identify types of land cover in the 1990 image, and decide which are pervious/impervious to water. *(10 min.)*

Explain

Step 6. Visually compare the 1990 and 2000 Landsat images and write about differences (change over time). *(10 min.)*

Step 7. Make a map of land cover types in 1990 using transparency with grid. *(10 min.)*

Elaborate

Step 8. Comparing the 1990 land cover map to the 2000 Landsat satellite image, count and record the numbers of grid squares representing land cover that have changed from pervious to impervious surfaces, or from impervious to pervious surfaces. *(15 min.)*

Step 9. Calculate the percent change from pervious to impervious surface area. *(5 min.)*

Evaluate

Step 10. Optional. If two or more student teams analyze change in the same geographic area, compare teams' results and comment on any differences. *(15 min.)*

Step 11. Respond to guiding questions provided. *(15 min. in class or homework)*

Step 12. Optional. Assuming the same rate and nature of change, make a predictive map of land cover in 2025. Describe and explain the 2025 map and any ecological consequences that might be expected from the change. *(15 min. in class or homework)*

Educators can conduct this activity using any pair of images that show the same place during the same month, several years apart.

Where to Find Pairs of Images for Quantifying Changes in the Land Over Time

USGS Landsat Image Gallery

http://landsat.usgs.gov/gallery.php

Array of images including Earth features such as volcanoes, floods, and cities

World of Change

http://earthobservatory.nasa.gov/Features/WorldOfChange/

Pairs of images useful for analyzing change over time

Landsat Resource Gallery – NASA's Scientific Visualization Studio server

http://svs.gsfc.nasa.gov/Gallery/Landsat.html

Contains links to many videos, animations, and visualizations of Landsat data

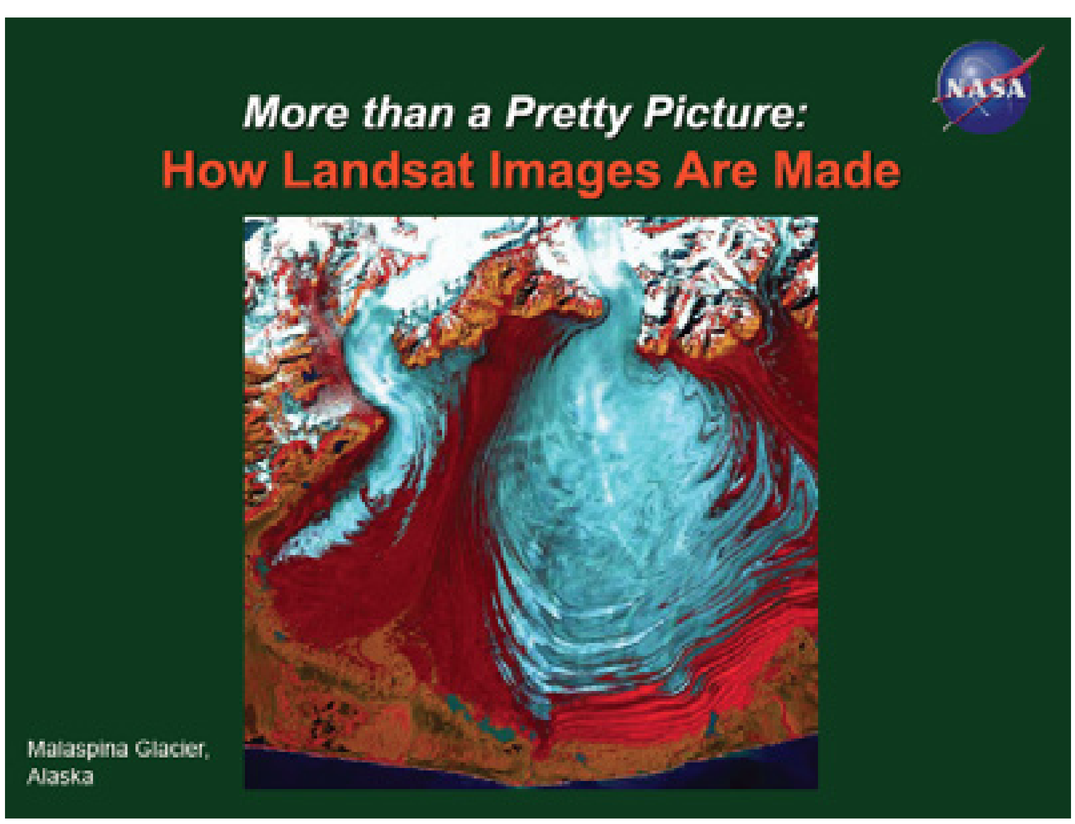
Scene Changes

http://www.scenechanges.org/

Landscapes featured in literary works, with discussions on how they have changed and why.

Important Educator Background on Landsat

See separate file (pdf), *More than a Pretty Picture: How Landsat Images Are Made*.



Chapter IV

Classroom Materials, Level 2 (computer-based):

Using Free Software to Analyze Changes in the Land Over Time

For Introductory-level learners with basic computer skills can take advantage of existing tutorials, free software, and free data to do electronically what students do with printed images in the activity in Level 1 of this Guide, that is, to analyze satellite data in order to quantify changes in the land and how we use it over time.

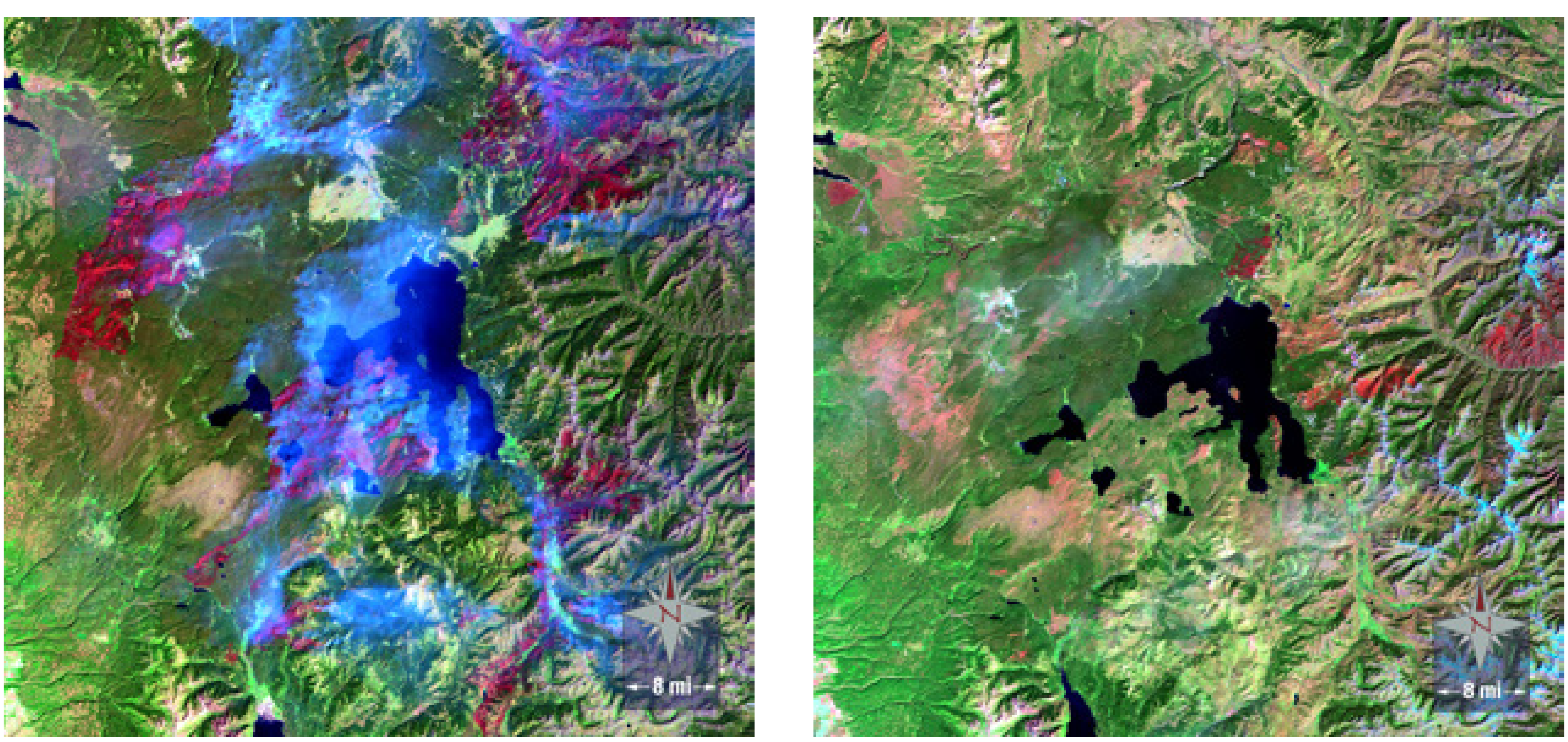
Remember that doing this part of the work requires learners understanding the imaging process of Landsat sensors. Make sure to provide that understanding to students before asking them to analyze Landsat data.

About the Data

All Landsat data are available to the public at no cost at U.S. Geological Survey website, the Global Visualization Viewer: http://glovis.usgs.gov
Available data includes the entire archive dating back to 1972.

Downloading Landsat data and combining bands to make your own images is not a difficult process but it can be intimidating for people who are not accustomed to learning new software. Don't lose heart if it doesn't work the first time!

- Part A. Finding and Downloading Landsat Data from USGS GloVIS Website
- Part B. Making Landsat Images Using Photoshop
- Part C. Making Landsat Images Using ImageJ (no-cost software)
- Part D. Using ImageJ to Analyze Changes in Land Over Time, From Eyes in the Sky II



These Landsat 7 images show the Yellowstone fire of 1988 (at left) and its stage of recovery 20 years later in 2008 (at right). They use Band 7 (mid-infrared), Band 4 (near infrared), and Band 2 (green). In the1988 image, green represents vegetation, red represents a burn scar, light magenta/brown represents soil, light blue represents smoke and dark blue represents water. In the 2008 image, green represents vegetation, red represents a burn scar, light magenta/brown represents soil and light blue represents snow and very dark blue/black represents water.

❖ Part A. Finding and Downloading Landsat Data from the U.S. Geological Survey's Global Visualization Viewer Website

All Landsat data are available to the public at no cost from U.S. Geological Survey (USGS) websites. Among these are:

Global Visualization Viewer (GloVIS): http://glovis.usgs.gov

LandsatLook: LandsatLook.usgs.gov

Earth Explorer: http://earthexplorer.usgs.gov

This tutorial describes all the steps for to get data from GloVIS.

A Quick Guide to Earth Explorer for Landsat 8 is available at:
http://earthobservatory.nasa.gov/blogs/elegantfigures/2013/05/31/a-quick-guide-to-earth-explorer-for-landsat-8/

SUMMARY

STEP 1. Register as a user of USGS data and create an account.

STEP 2. Log in (after registering).

STEP 3. Go to the USGS GloVIS website.

STEP 4: Select a satellite collection.

STEP 5. Find your scene of interest by clicking on the interactive map.

STEP 6. Add desired scenes to your list.

STEP 7. Order the scene(s) you have selected.

STEP 8. Uncompress the files (twice).

Before you begin, please note:

Landsat scenes are large files. Unzipped Landsat 5 and 7 scenes are about 450 megabytes, and Landsat 8 scenes are about 2 gigabytes. This is clearly an important consideration when downloading them.

Core Concept

Landsat scenes are made of several layers (bands) of data. Each band represents a section of the electromagnetic spectrum that has been selected because it is useful for distinguishing kinds of land cover and land use from one another, and for measuring the ways they change over time.

Landsat has looked at light reflected from the Earth in consistent ways since the first mission in 1972, with minor changes in the wavelength ranges assigned to bands. Landsat 5 and 7 wavelength ranges are quite similar. Landsat 8 added a band to see into coastal waters and a band to detect cirrus clouds.

A USGS website provides information about which wavelength ranges (bands) to use for any given area of study:

https://landsat.usgs.gov/best_spectral_bands_to_use.php

Before you use this tutorial

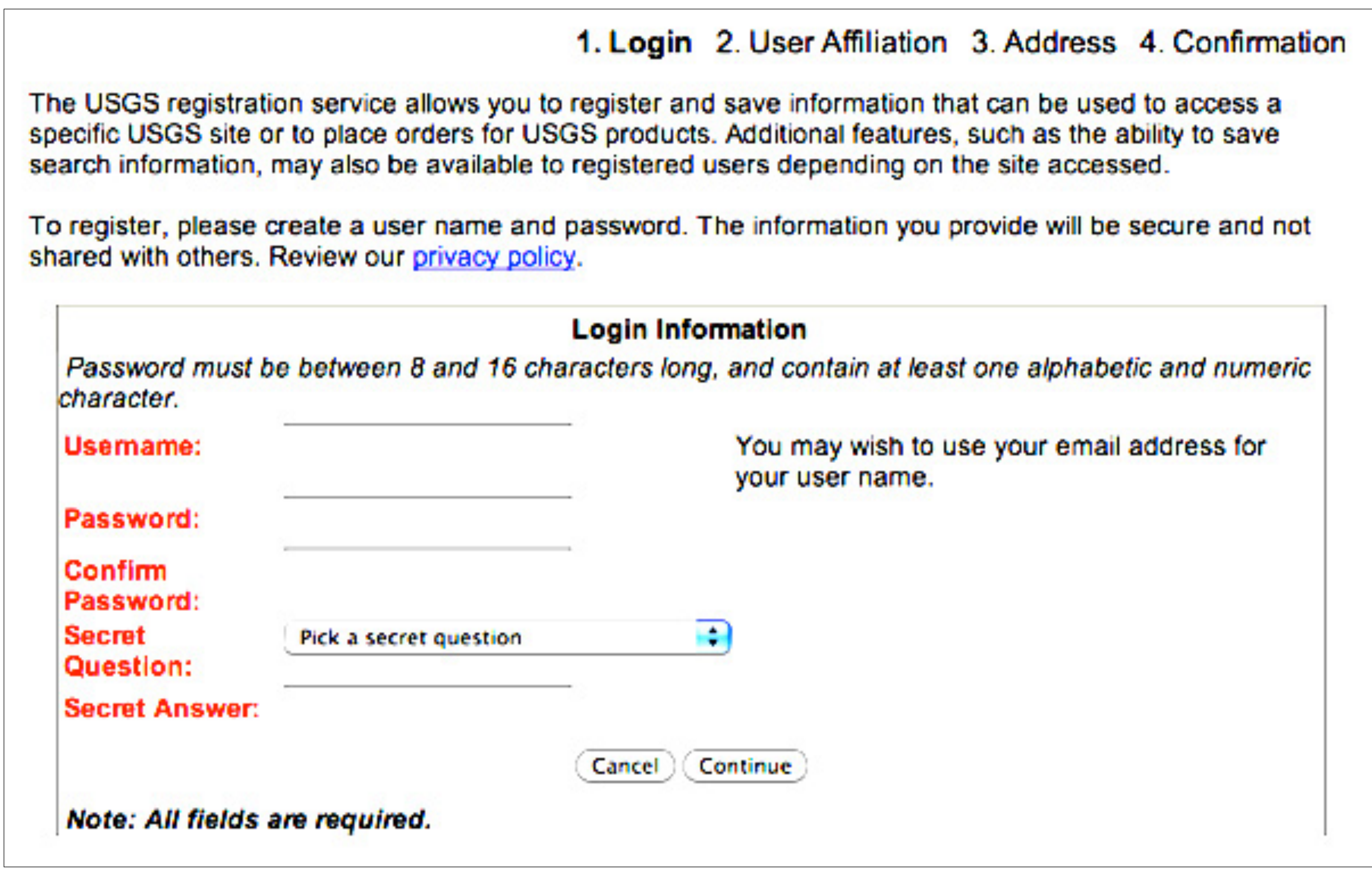
Please be aware that few websites remain exactly the same for long, and the USGS GloVIS website is no exception. The agency modifies its websites as time passes. So you may encounter slightly different screens or directions from those in this tutorial. If you have a question or need assistance, you can click on the "Contact USGS" link at upper right of the GloVIS page.

STEP 1. Register as a user of USGS data and create an account.

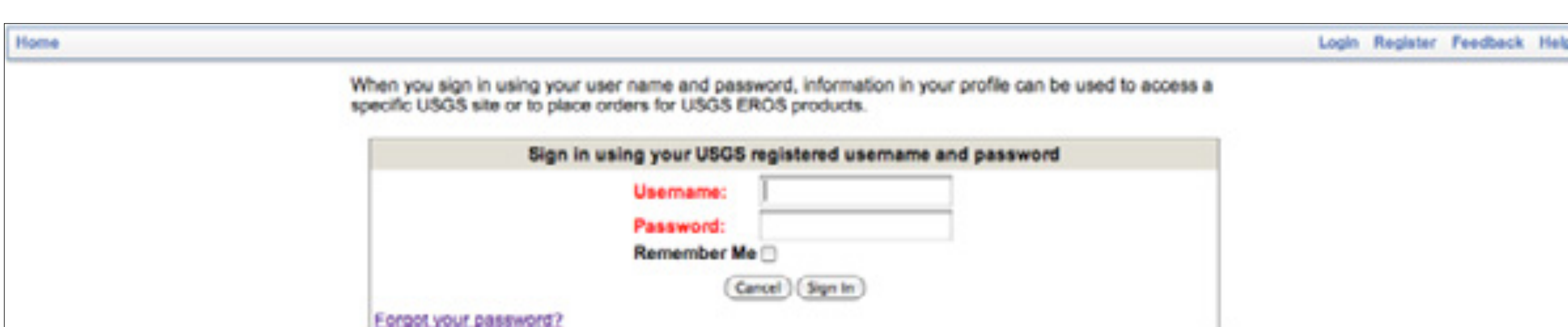
To be able to download data from either GloVIS or Earth Explorer sites, you must first register and create an account.

To register and create an account, go here:
https://earthexplorer.usgs.gov/register/?return

TIP: Be sure to register *prior to* starting your search for Landsat scenes on GloVIS because the system will not let you download any data unless you are logged in. Screen 1 of a 4-screen login/registration process appears below.



STEP 2. Log in (after registering).



STEP 3. Go to the USGS GloVIS website:

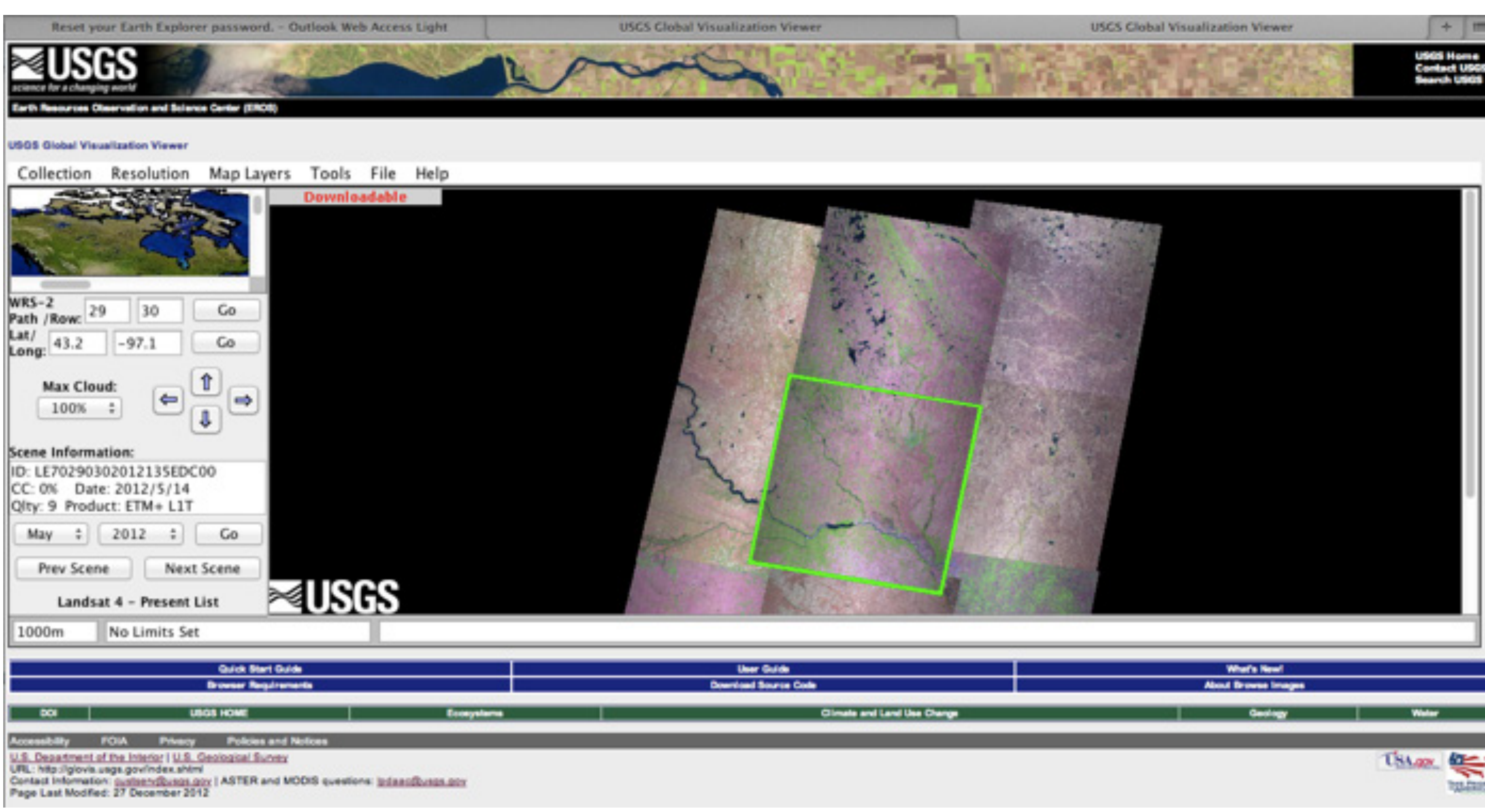
http://glovis.usgs.gov

Make sure that –

- *Your pop-up blockers are off.*
- *Java is enabled.*
- *Your software is updated. See "System Notices" on the GloVIS site.*

A window may appear in which you are asked if you want to run the USGS viewer. Choose "Run."

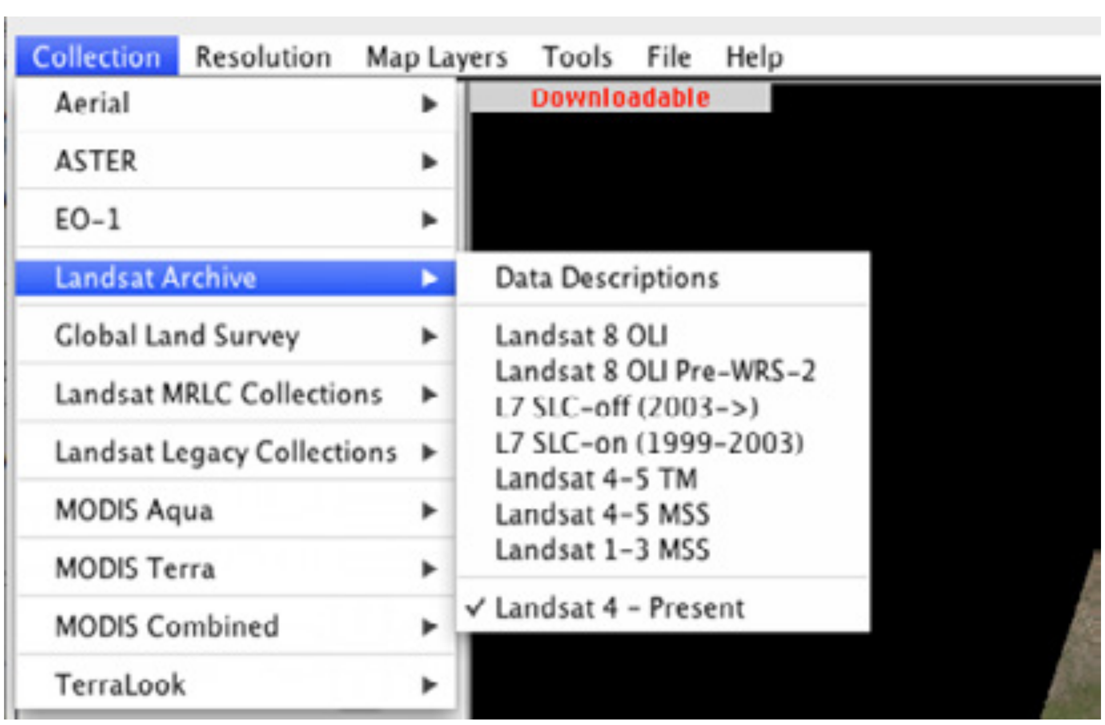
When you first open GloVIS, you will see a screen like the one below.



You will see a map at upper left of that screen (under "Collection" and "Resolution").

STEP 4: Select a satellite collection.

Above the map, see "Collection." Pull that menu down; choose "Landsat Archive" and, next to it, "Landsat 4 - Present."



TIPS

» Available data includes the entire archive dating back to 1972. The data for best comparability with current dates and best data quality begins with Landsat 5 in 1984.

» In order to get to the first three Landsat satellite's data you will need to navigate to "Collection" at the top of the application, then to "Landsat Archive" and finally to "Landsat 1-3," and select it. The data from Landsat 1-3 extend from 1972 to 1982. Note however, that the scenes are smaller and the image quality may not be as consistently high as in more recent Landsat scenes.

PLEASE NOTE: The following guidelines apply only to the Landsat 5-8 portions of the data archive, not to Landsat scenes taken before 1984.

STEP 5. Find your scene of interest by clicking on the interactive map.

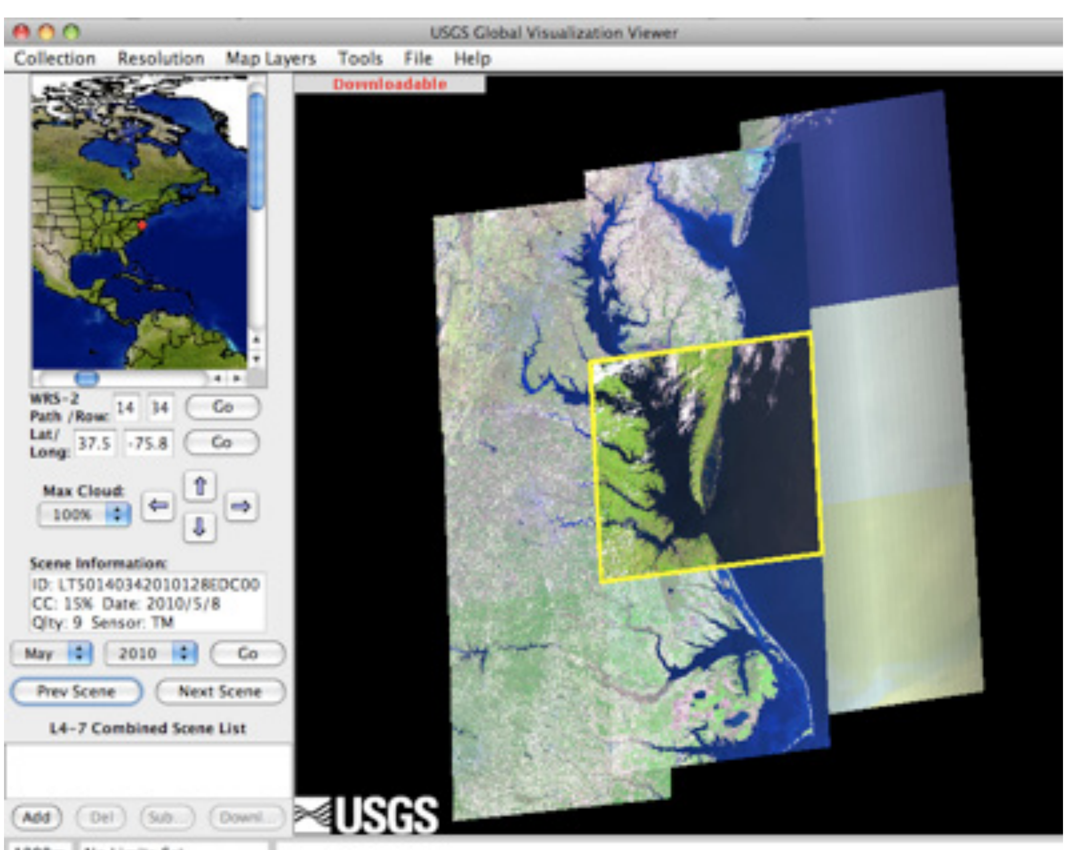
You should be able to find at least one Landsat scene of any region of interest because there is a Landsat scene for every location on Earth's lands between ~82° N and S. Each Landsat scene covers a region approximately 182 km x 185 km (113 x 115 miles).

This window may appear:

Click on "Allow."

TIP
You may wish to turn on city names in "Map Layers" (near top) in order to help locate your scene of interest.

The example in this tutorial uses part of a peninsula on the east coast of the United States called the Delmarva Peninsula. ("Del-mar-va" refers to Delaware, Maryland, and Virginia.)



To help find the scene of interest, you can select the "Map Layers" menu on the menu bar. You will then be able to view administrative boundaries, country boundaries, the collection grid, roads, water, north arrow, and/or World Cities (and others).

You can also use latitude and longitude. Lat/long can be found by an Internet search if needed.

You can choose to view scenes from other dates by changing the month or year and clicking on "Go," or by clicking on "Prev Scene" or "Next Scene."

Scene Identification Window

WRS-2: *Worldwide Reference System (WRS) refers to the global notation for Landsat data. See "path/row" below.*

Path/Row: *As the spacecraft moves along its path, the sensor scans the terrain below. A grid system of paths and rows (the WRS) is used to provide a reference number for each scene. In the case of this particular scene, the path is 14, and the row is 34.*

Lat/Long: *Each path and row grid can be identified by its latitude and longitude as well as by its path and row.*

Max Cloud: *Landsat sensors do not see through clouds. You can choose what percentage of a scene you are willing to have covered by clouds. If you choose "30%," the GloVIS search function will show you only scenes with 30% or less cloud coverage.*

Scene Information:
ID: LC80340342014071LGN00 (Example)

CC: *Cloud cover. 8% means clouds cover 8% of the scene. Landsat sensors cannot see through clouds. Choose the lowest percent of cloud cover you will accept here.*

Date: *This is the date when the scene was acquired: year/month/day – So in the case of the example here, 2010 is the year; 5 is the month (May); and 8 is the day.*

Qlty: *9: Quality ranges from 0-9 with 9 being the best.*

Sensor: *This tells you what instrument on the satellite acquired the image. If it says "TM" it refers to Landsat 4 or 5's Thematic Mapper. If it says "ETM+" it refers to Landsat 7's Enhanced Thematic Mapper*

The word, "Downloadable" may appear in red in the upper left-hand corner of the scene itself. That usually – but not always – means you can download the scene right away without having to order – and wait for – it from USGS.

<u>Resolution.</u> If you click on "Resolution," near the top of the screen, you will see a drop-down menu that offers both 1000 m and 240 m resolution. Toggle back and forth and see what changes.

Don't worry too much about this Scene Information ID number! You DO need to know that –

The third character in the Scene Information ID number tells you which satellite acquired the scene.

So in this case, "LT5" indicates that the scene was acquired by the Landsat 5 satellite (not Landsat 4, 7 or 8).

Optional: More about Scene Information ID number

All Landsat scene identifiers are based on the following naming convention:
LXSPPPRRRYYYYDDDGSIVV
- L = Landsat
- X = Sensor
- S = Satellite
- PPP = WRS path
- RRR = WRS row
- YYYY = Year
- DDD = Julian day of year
- GSI = Ground station identifier
- VV = Archive version number

Examples:

LC80390222013076EDC00	(Landsat 8 OLI and TIRS)
LO80390222013076EDC00	(Landsat 8 OLI only)
LT80390222013076EDC00	(Landsat 8 TIRS only)
LE70160392004262EDC02	(Landsat 7 ETM+)
LT40170361982320XXX08	(Landsat 4 TM)
LM10170391976031AAA01	(Landsat 1 MSS)

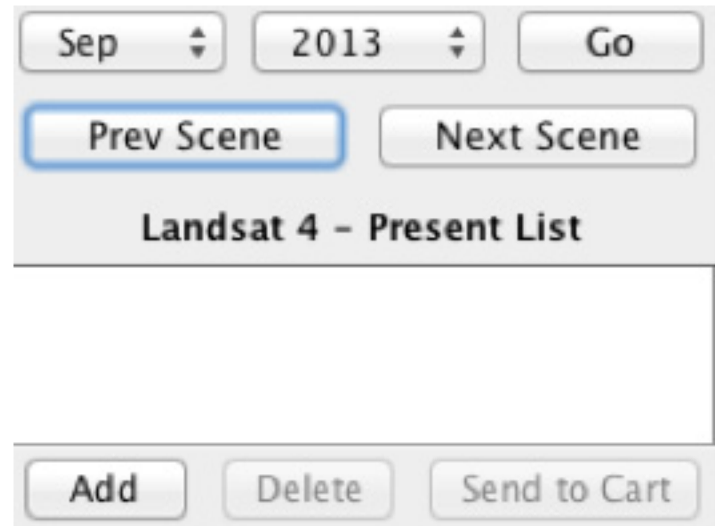
From: USGS Frequently Asked Questions at:
https://landsat.usgs.gov/naming_conventions_scene_identifiers.php

See stripes in this Landsat 7 image where data are missing from both sides. In late May 2003, the ETM+ instrument's Scan Line Corrector (SLC) failed. "SLC-off" indicates scenes including that failure, all Landsat 7 scenes after May 30, 2003.

A Note about Stripes in Landsat 7 Scenes. Landsat 7's sensor (Enhanced Thematic Mapper +) developed a problem in May 2003 that causes striping from a lack of data on both sides of the scene–though not in the middle. USGS has data products to deal with the issue. But for this introductory level, unless the area you want to study is in the center of the scene, you will want to use only Landsat 7 scenes taken before May 30, 2003, and/ or Landsat 5 or Landsat 8 scenes.

STEP 6. Add desired scenes to your list.

(a) Make sure each scene you want is selected within the yellow box, then click "Add," near the lower left of the screen. That scene number will appear in a box below called, "Landsat 8 OLI Scene List."



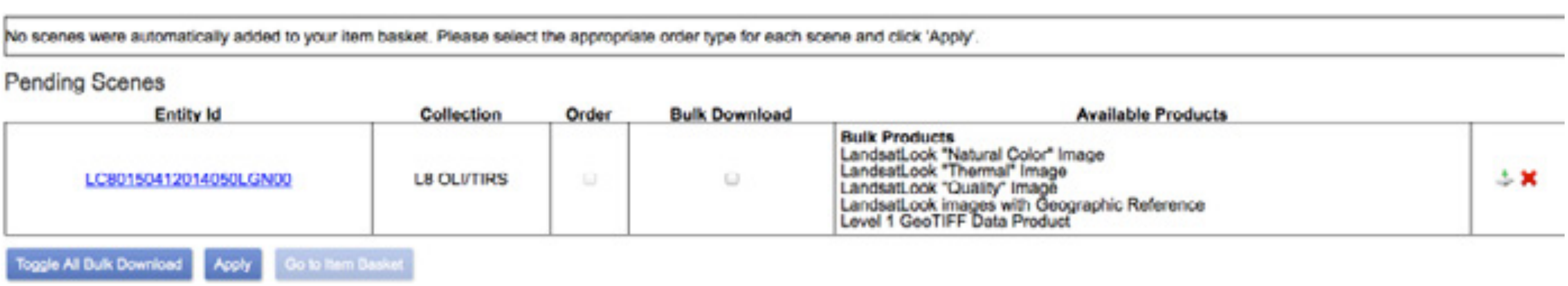
Deleting scenes from your list:

If you decide you don't want a given scene after all, you can click on it and then on "Del" or "Delete" to remove it from your list.

To download a scene, see that it is selected within the yellow highlighted box, then click "Add" at the lower left hand corner of the screen.

Tip
If you can't see the window called, "Landsat 4 - Present List," go to "View," pull down and choose, "Actual Size."

(b) Click on "Send to Cart." This will cause a new window to open with the scene information.



STEP 7. Download or order the scene(s) you have selected.

TIP
Time required to download: As mentioned above, Landsat scenes, particularly those from Landsat 8, are large files and may take a long time to download.

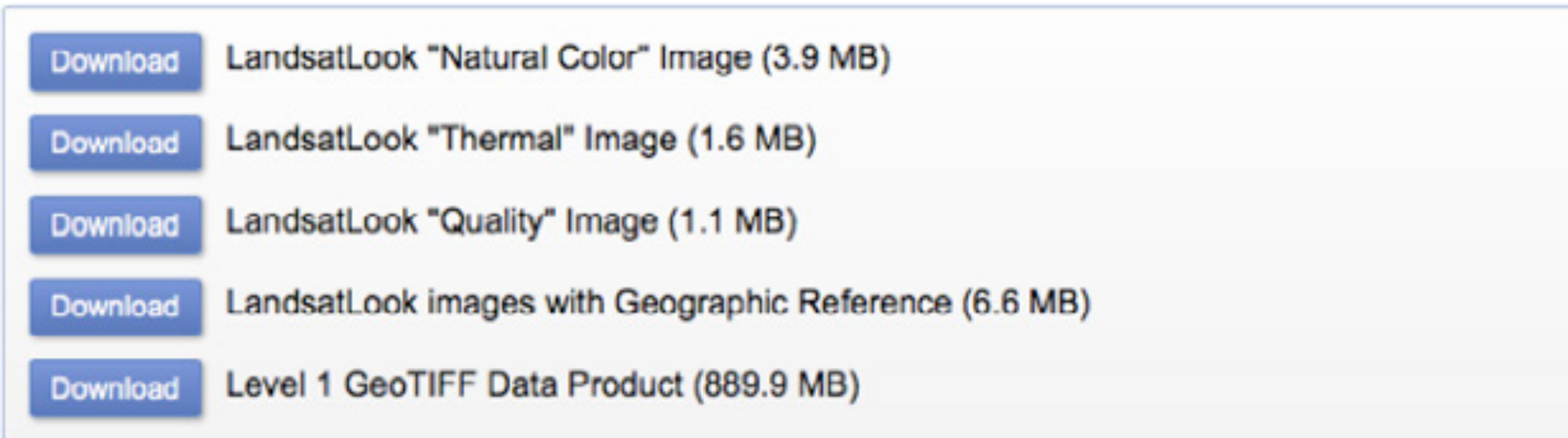
» If "Downloadable" appears in red font in the upper left corner of the browse image, you can download it right away.

» If "Downloadable" does NOT appear on the upper left-hand corner of the scene, you will need to order the scene from USGS. To do this go to Step 7C below. Getting your ordered scene will take one or two business days.

7A. To obtain a "Downloadable" scene, click on the green download arrow at right of the screen.

(Clicking on the red X will delete the scene from your order.)

The Download Options window will appear.



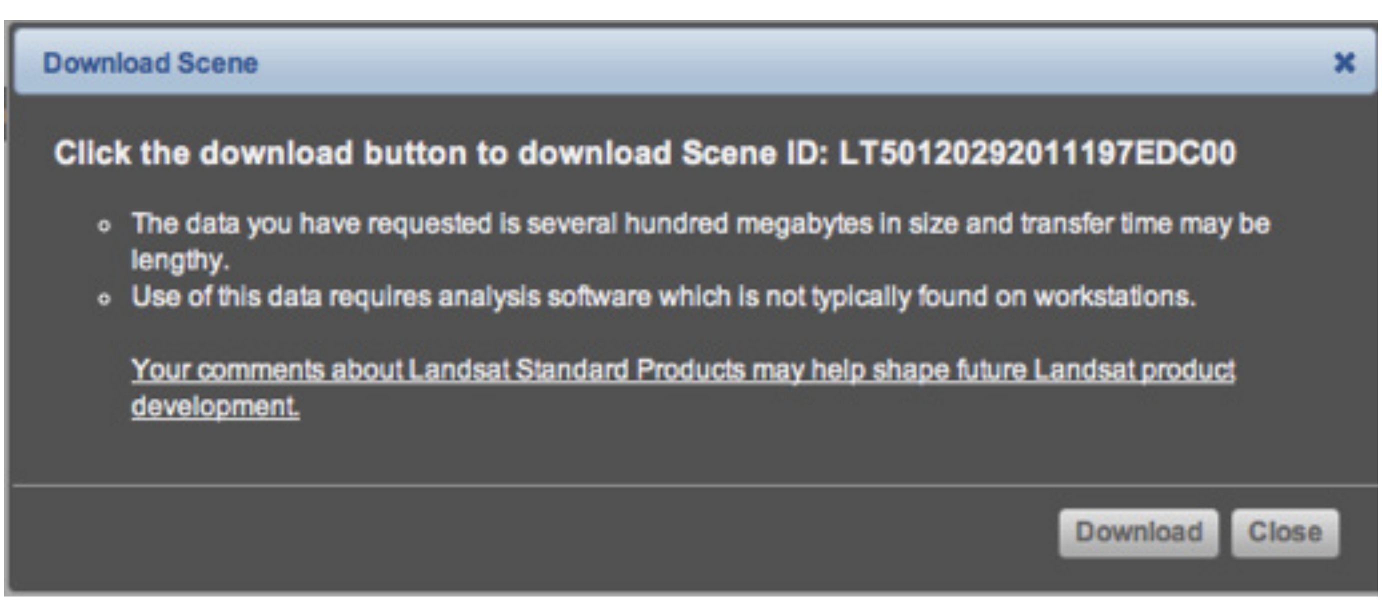
About the Download Options:

If all you require is a natural color image (one that looks like you might take it from a simple camera in space) select the LandsatLook "Natural Color" Image and finish by clicking the "Select Download Option."

LandsatLook Images

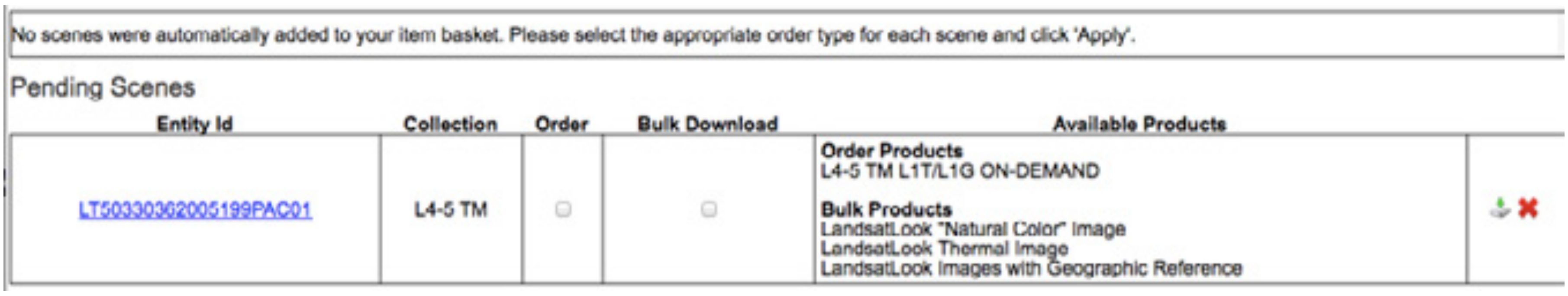
LandsatLook images are full resolution ready-made Landsat images. More specifically, they are JPEG files derived from Landsat Level 1 data products. They are available as pseudo-natural color images or as thermal grey-scale images. The images are compressed and stretched to create an image optimized for image selection and visual interpretation. LandsatLook images are very useful if you want a full-resolution image, but if you do not want to download the full data set and make a composite RGB image yourself.

If you want to composite your own image, selecting wavelength ranges or bands of your choice, you need all data layers in your scenes. Select the last option in the Download Options menu, **Level 1 GeoTIFF Data Product.**



B. Choose the data product you want to download, and click on that "Download" button.

C. To obtain scenes that are not immediately Downloadable, after you click on "Send to cart" in Step 6, you will see a window like the one below.



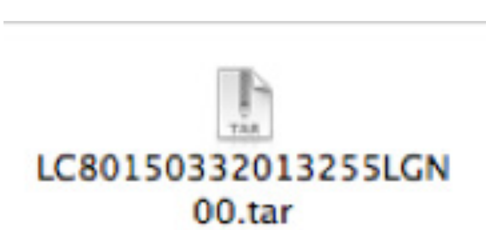
1. Click on "Order"
2. Click on "Apply
3. Click on 'Go to item basket."
4. Click on "Proceed to check out" in the window like the one below.

5. Click on "Submit order." When the data are ready (in a matter of days) you will receive an e-mail message from the U.S. Geological Survey indicated how to retrieve it.

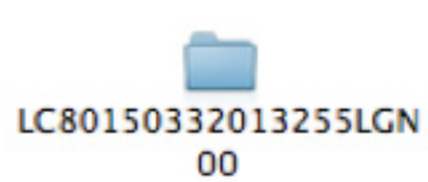
STEPS FOR OPENING THE SCENE

STEP 8. Uncompress the files – twice! – using zip software.

The files will be compressed in a zip file.



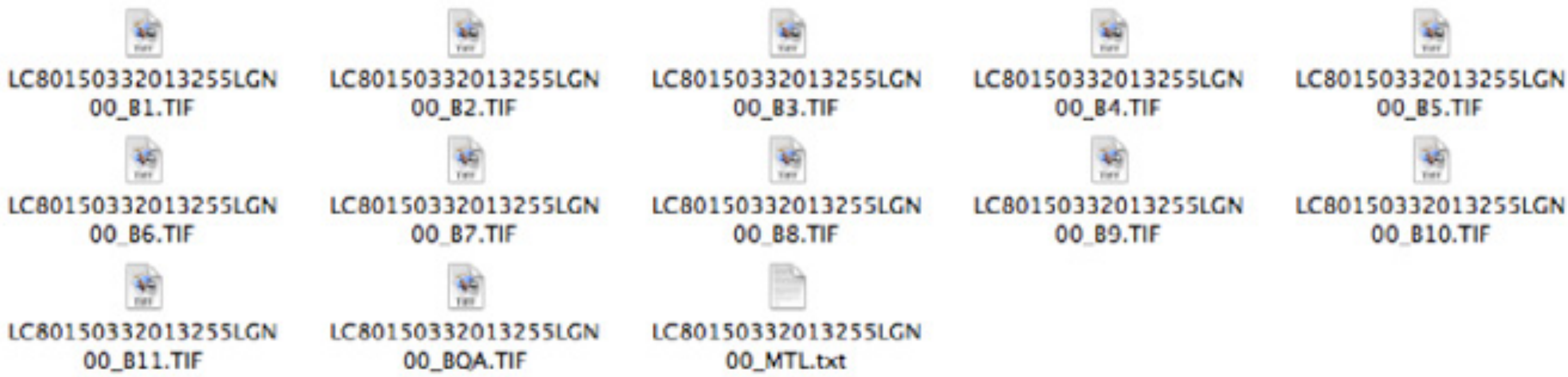
Uncompress them using zip software. Unzip twice!



TIP

Several software packages exist for this purpose and can be found by a Web search.

Your unzipped folder contents will look like this (Landsat 8 files):



Each of the files whose name ends in "TIF" holds the data from one Landsat band.

Remember the Core Concept: Landsat scenes are made of several files or layers (bands) of data. Each band represents a section of the electromagnetic spectrum that has been selected because it is useful for distinguishing kinds of land cover and land use from one another, and for measuring ways they change over time.

To make Landsat images from these downloaded data files in band combinations of your choice, see one of these other tutorials: "Making Landsat Images Using ImageJ;" or, "Making Landsat Images Using Photoshop."

To learn more about Landsat scenes, go to:

Fundamentals of Remote Sensing
http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1430

References:

- EarthExplorer Tutorial: https://lta.cr.usgs.gov/ee_help
- EarthExplorer Registration: https://earthexplorer.usgs.gov/register/
- GloVis Quick Start Guide: http://glovis.usgs.gov/QuickStart.shtml
- LandsatLook Viewer User Documentation: http://landsat.usgs.gov/LandsatLook_Viewer.php
- Landsat Data Products: http://landsat.usgs.gov
- LandsatLook Images: http://landsat.usgs.gov/LandsatLookImages.php

USGS Landsat User Services

Contact USGS Landsat User Services with any questions regarding these interfaces or Landsat data products, M-F 8:00 am to 4:00 p.m. CT:
landsat@usgs.gov
1-605-594-6151
1-800-252-4547

❖ Part B. Making Landsat Images in Adobe Photoshop

Please Note:
All the Landsat data you want to work with should be downloaded before you begin this tutorial.

To learn how to download Landsat data from U.S. Geological Survey's GloVIS, see a separate tutorial, Finding and Downloading Landsat Data from the U.S. Geological Survey's Global Visualization Viewer Website.

TUTORIAL SUMMARY

Step 1. Open Photoshop.

Step 2. Open three bands of data.

Step 3. Merge the bands of data (channels).

Step 4. Choose which channels (bands) should appear in your final image in tones of red, green, and blue.

Step 5. Adjust color levels.

Step 6. Set white and black points in your image.

Step 7. Sharpen the image.

Step 8. Save the image as a .tiff file.

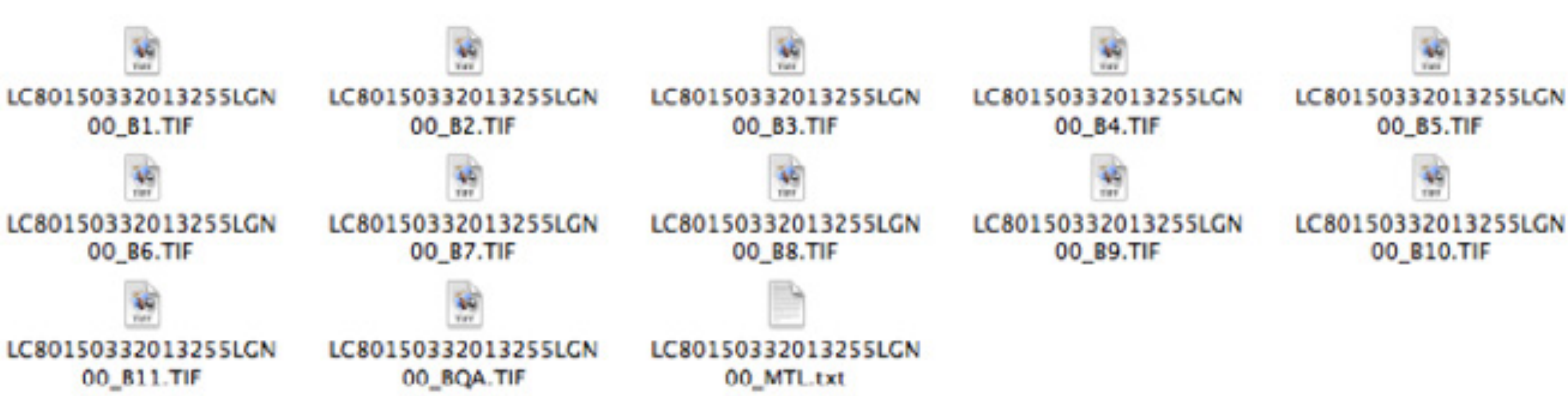
Before you begin:

Landsat scenes are large files. Unzipped Landsat 5 scenes are about 404 megabytes (MB), and Landsat 7 scenes are about 654 MB. This is an important consideration when downloading or manipulating them.

Core Concept

Landsat scenes are made of separate layers or files (bands) of data. Each band represents a section of the electromagnetic spectrum that has been chosen for Landsat because it has proven to be useful for distinguishing different types of land cover and land use from one another, and for measuring the ways they change over time.

Your unzipped Landsat 8 scene will give you separate files for each band, as in the illustration below.



Landsat has looked at light reflected from the Earth in consistent ways since the first mission in 1972, with minor changes in the wavelength ranges assigned to bands. Landsat 5 and 7 bands are quite similar. Landsat 8 added a band to see into coastal waters and a band to detect cirrus clouds.

Important Background:

Landsats 5 and 7 bands differ somewhat from Landsat 8 bands. Landsat 8 added a couple of bands to the ones used by Landsats 5 and 7:

– a deep blue visible band (Band 1) specifically designed for water resources and coastal zone investigations, and

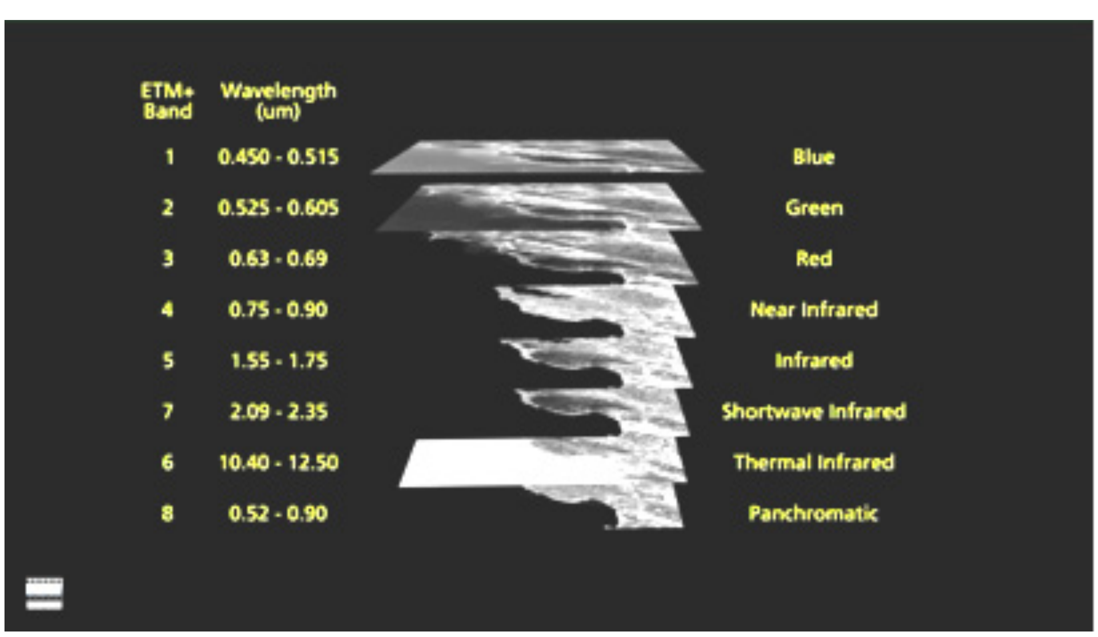
– a new infrared band (Band 9) for the detection of cirrus clouds.

– two thermal bands (Bands 10 and 11), which were covered by a single band on Landsat 5 & 7.

Bands	Landsats 5 & 7	Landsat 8
Band 1	*Blue*	*Coastal Penetration*
Band 2	*Green*	*Blue*
Band 3	*Red*	*Green*
Band 4	*Near Infrared*	*Red*
Band 5	*Shortwave Infrared 1*	*Near Infrared*
Band 6	*Shortwave Infrared 2*	*Shortwave Infrared 1*
Band 7	*Thermal Infrared*	*Shortwave Infrared 2*
Band 8		*Panchromatic*
Band 9		*Cirrus cloud detection*
Band 10		*Thermal Infrared 1*
Band 11		*Thermal Infrared 2*

One More Thing about improvements of Landsat 8 over Landsats 5 & 7:

Landsat 5 & 7 measure reflected light on a scale of 0-255.
Landsat 8 measures light on a scale of 0 to 4,095.
So with Landsat 8 we can see many more shades of the light we are measuring, and we can study greater nuance in our scenes of interest.



Landsat scenes include data from both visible and infrared wave-length ranges. These are the wavelength ranges of Landsat 7.

Step 1. Open Photoshop.

Step 2. Open three bands of data.

Note: Your choice of bands will depend on whether you want to see just visible light, infrared light, or a combination of visible and infrared.
If you are using Landsat 8 data and want an image in visible wavelengths, open bands 2, 3, and 4. If you are using Landsat 5 or 7 data and want an image in visible wavelengths, open Bands 1, 2, and 3.

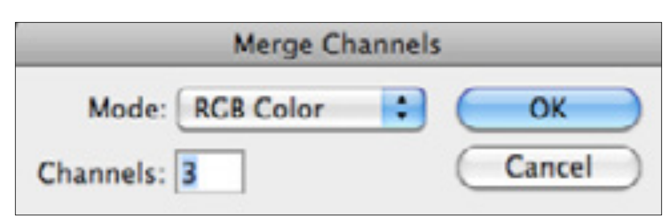
Assuming you are using Landsat 8 data and want an image in visible wavelengths:
Open Band 2. The file name ends with B2.
Open Band 3. The file name ends with B3.
Open Band 4. The file name ends with B4.

Please note: In this tutorial, "Channel" and "Band" are equivalent terms.

Step 3. Merge the bands of data (channels).

1. Go to the "Window" menu and select "Channels." In the Channels box, click on the very small menu icon (four horizontal lines) in the upper right corner.

2. Select "Merge Channels" from that pull-down menu.
3. Set Mode to RGB Color



4. Set Channels to 3, and click "OK." A window titled, "Merge RGB Channels" will appear.

Step 4. Choose which channels (bands) should appear in your final image in tones of red, green, and blue.

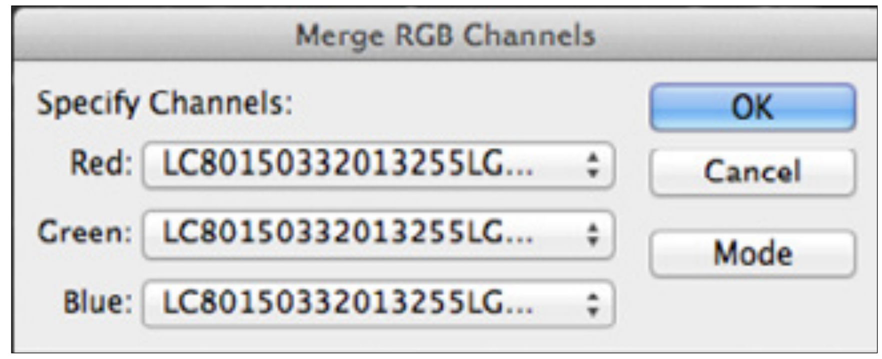
To make your final image appear as close as possible to its appearance if seen with our own eyes, you will use Landsat's visible wavelength ranges (bands, or channels).

Select Band 4 for the red channel.

Select Band 3 for the green channel.

Select Band 2 for the blue channel.

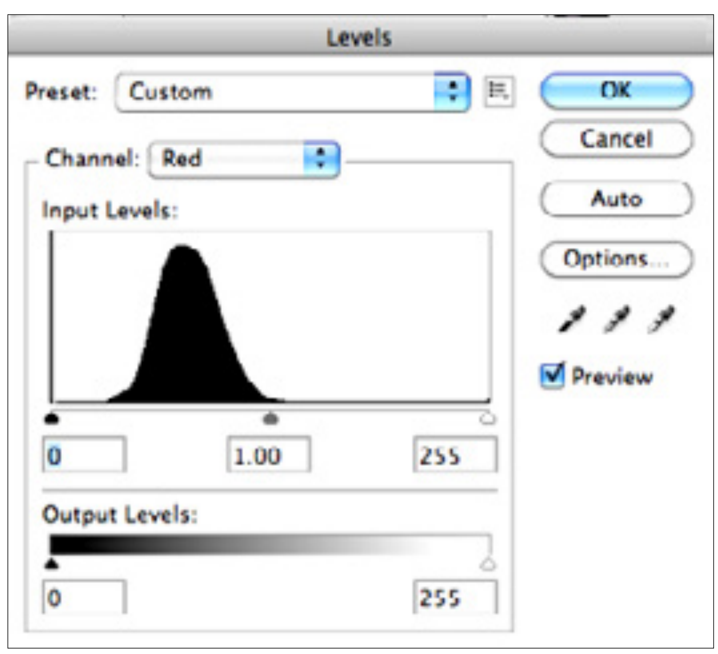
Click "OK."



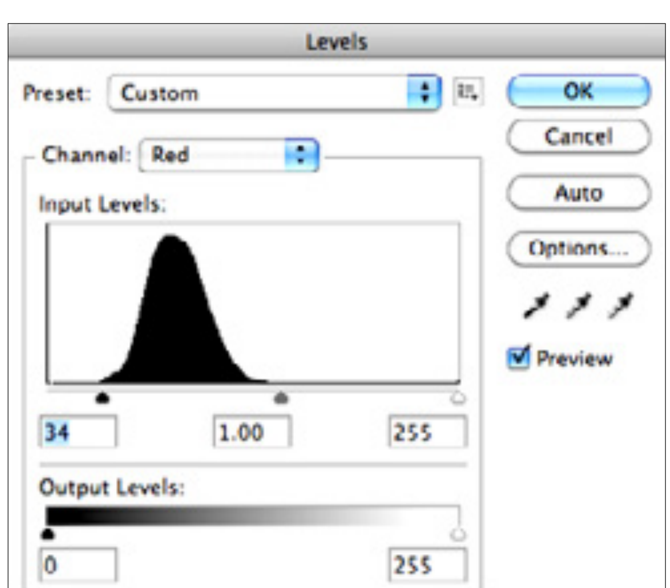
Don't worry if the resulting colors don't appear exactly as you want them! You can fix the color balance following the steps below.

Step 5. Adjust color levels.

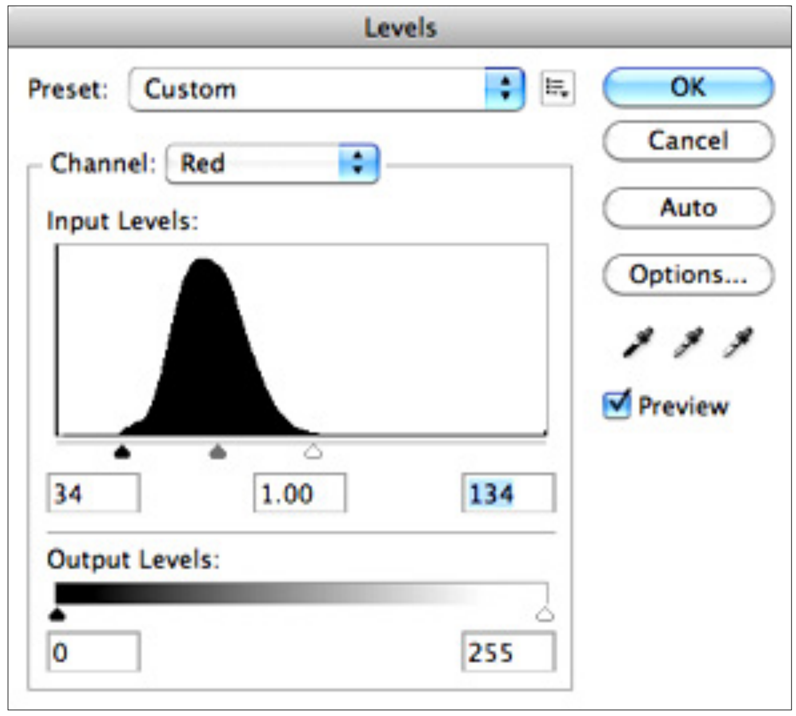
a. Go to the Image menu in the top navigation bar and select "Adjustments" and then "Levels." In the Levels box under "Channel," select "Red."



Grab the far left arrow under the histogram with your cursor and slide the arrow so it touches the left side of the bulk of the data as shown by the curve. Example below.



Slide the far right arrow under the histogram so it touches the right side of the bulk of the data. (Ignore the central arrow.)



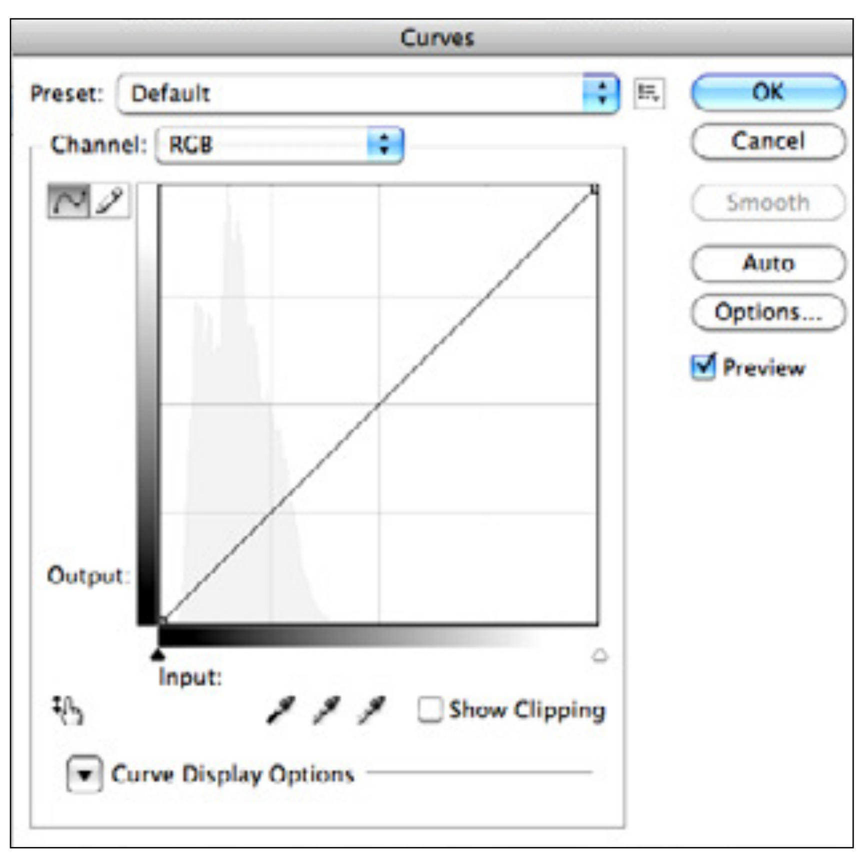
b. Under "Channel," select "Green," and repeat the adjustment by arrows; then do the same for the Blue Channel.
Click "OK."

You can go through this color level changing process as many times as you wish to get the color balance you want.

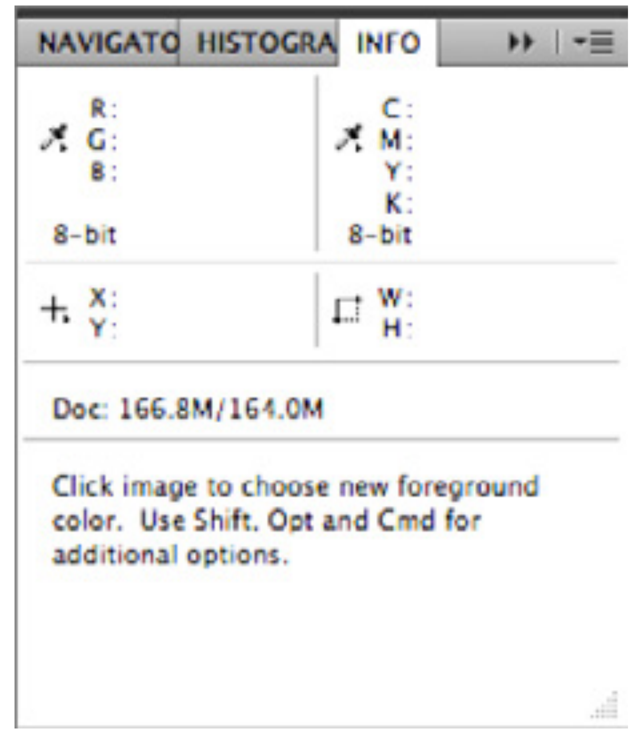
<u>Step 6. Set white (lightest) and black (darkest) points in your image.</u>

a. Go to the Image menu at top and pull down to select "Adjustments," then "Curves."

This box will open:



b. Go to the Window menu in the top navigation and select Info. The Info box will open.



c. In the Curves box under the graph, select the third eye dropper.
(If you hover over it, it will say "Sample in image to set white point.")
Place the eyedropper over a white point, such as a cloud, in the image. As you do so, watch the Info box. The RGB values will change as you move the eyedropper. Look for a point for which all three values approach (but aren't at) 255. Once you've identified such a point, click to select it.

d. Select the first eyedropper. Place the eyedropper on a black point in the image.
A shadow is a good candidate for this black point. In the Info box, the RGB values should approach, but not reach, zero. Click on the point to set the black point.

e. If you wish, you can also adjust the brightness of the image by going to the Image menu, select Adjustments, then Brightness.

Step 7. Sharpen the image.

Go to "Filter," and pull down to "Sharpen."

Step 8. Save the image as a .tiff file.

You're done!
You can follow these same steps to make Landsat images in different band combinations.

Useful Band Combinations for Landsat 8:

- Natural Color: 432
- False Color (urban): 764
- Color Infrared (agriculture): 652
- Atmospheric Penetration: 765
- Healthy Vegetation: 562
- Land/Water: 564
- Natural with Atmospheric Removal: 753
- Shortwave Infrared: 754
- Vegetation Analysis: 654

Useful Band Combinations for Landsats 5 and 7:

» Natural Color: 321
» Near Infrared or NIR, or 432
» Short-Wavelength Infrared (SWIR), or 742

LEARNING MORE

Article with more tips and guidance: How To Make a True-Color Landsat 8 Image [using Photoshop]
http://earthobservatory.nasa.gov/blogs/elegantfigures/2013/10/22/how-to-make-a-true-color-landsat-8-image/

To learn more about Landsat and other remote sensing data, study this tutorial:
Fundamentals of Remote Sensing
http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1430

❖ Part C. Making Landsat Images Using ImageJ

<No-cost Software>

Please Note

All the Landsat data you want to work with should be downloaded before you begin this tutorial.

To learn how to download Landsat data from U.S. Geological Survey's GloVIS, see a separate tutorial, Finding and Downloading Landsat Data from the U.S. Geological Survey's Global Visualization Viewer Website.

About ImageJ

ImageJ is free public domain image processing software developed at the National Institutes of Health. People can use ImageJ to display, annotate, edit, calibrate, measure, analyze, process, print, and save raster (row and column) image data. It reads most common raster image formats as well as raw data files in text format, such as from spreadsheets. ImageJ also supports stacks - multiple images in a single window - for animation and analysis.
Installers are available for Windows, MacOS and OSX, and Linux.

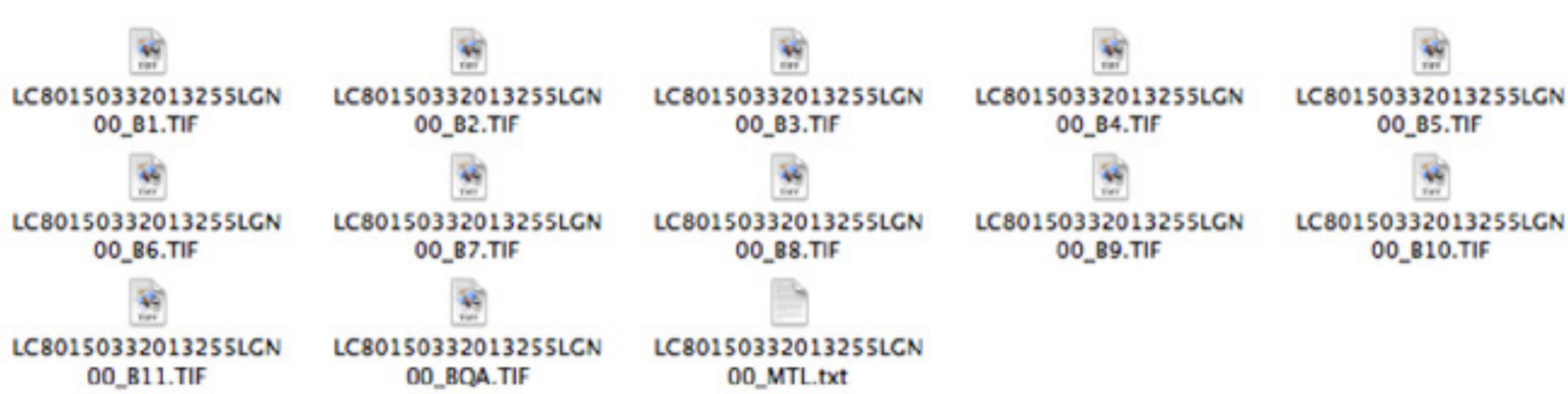
Before you begin:

Landsat scenes are large files. Unzipped Landsat 5 scenes are about 404 megabytes (MB), and Landsat 7 scenes are about 654 MB. This is an important consideration when downloading or manipulating them.

Core Concept

Landsat scenes are made of separate layers or files (bands) of data. Each band represents a section of the electromagnetic spectrum that has been chosen for Landsat because it has proven to be useful for distinguishing different types of land cover and land use from one another, and for measuring the ways they change over time.

Your unzipped Landsat 8 scene will give you separate files for each band, as in the illustration below.



Landsat has looked at light reflected from the Earth in consistent ways since the first mission in 1972, with minor changes in the wavelength ranges assigned to bands. Landsat 5 and 7 bands are quite similar. Landsat 8 added a band to see into coastal waters and a band to detect cirrus clouds.

Important Background:

Landsats 5 and 7 bands differ somewhat from Landsat 8 bands. Landsat 8 added a couple of bands to the ones used by Landsats 5 and 7:

– a deep blue visible band (Band 1) specifically designed for water resources and coastal zone investigations, and

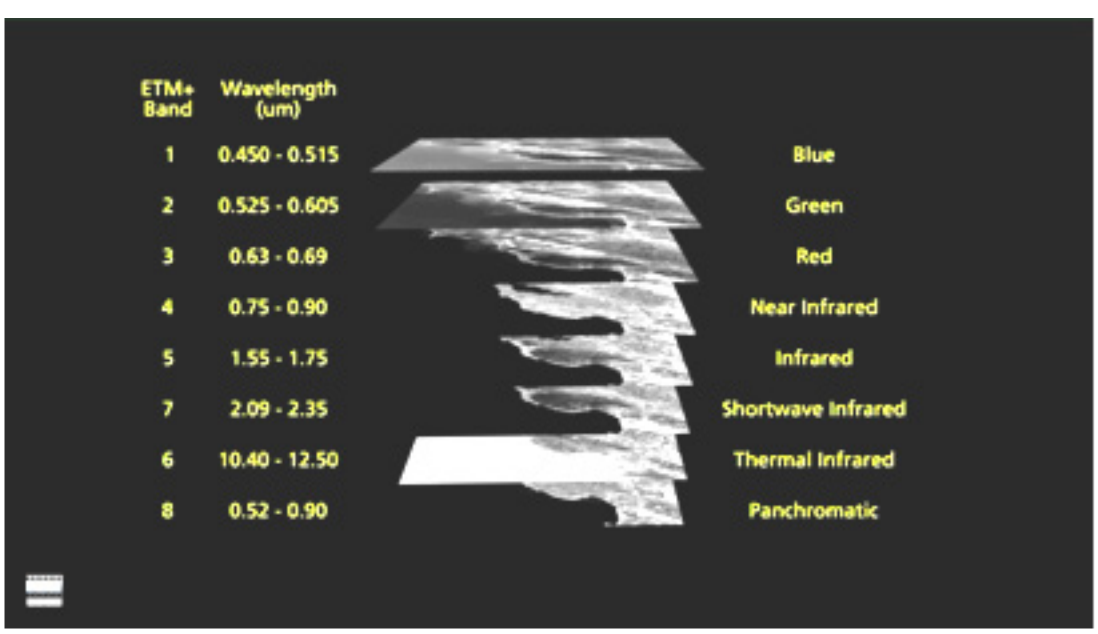
– a new infrared band (Band 9) for the detection of cirrus clouds.

– two thermal bands (Bands 10 and 11), which were covered by a single band on Landsat 5 & 7.

Band 1		*Coastal Penetration*
Band 2		
Band 3		
Band 4	*Near Infrared*	
Band 5	*Shortwave Infrared 1*	*Near Infrared*
Band 6	*Shortwave Infrared 2*	*Shortwave Infrared 1*
Band 7	*Thermal Infrared*	*Shortwave Infrared 2*
Band 8		*Panchromatic*
Band 9		*Cirrus cloud detection*
Band 10		*Thermal Infrared 1*
Band 11		*Thermal Infrared 2*

One More Thing about improvements of Landsat 8 over Landsats 5 & 7:

Landsat 5 & 7 measure reflected light on a scale of 0-255.
Landsat 8 measures light on a scale of 0 to 4,095.
So with Landsat 8 we can see many more shades of the light we are measuring, and we can study greater nuance in our scenes of interest.



Landsat scenes include data from both visible and infrared wave-length ranges. These are the wavelength ranges of Landsat 7.

More about using ImageJ can be found on the program website, Eyes in the Sky II, as indicated in the section below, "Going Further with ImageJ."

Please note:
All the Landsat data you want to work with should be downloaded before you begin this tutorial.

To learn how to download Landsat data from U.S. Geological Survey's GloVIS, see a separate tutorial, *Finding and Downloading Landsat Data from the U.S. Geological Survey's Global Visualization Viewer Website.*

TUTORIAL SUMMARY

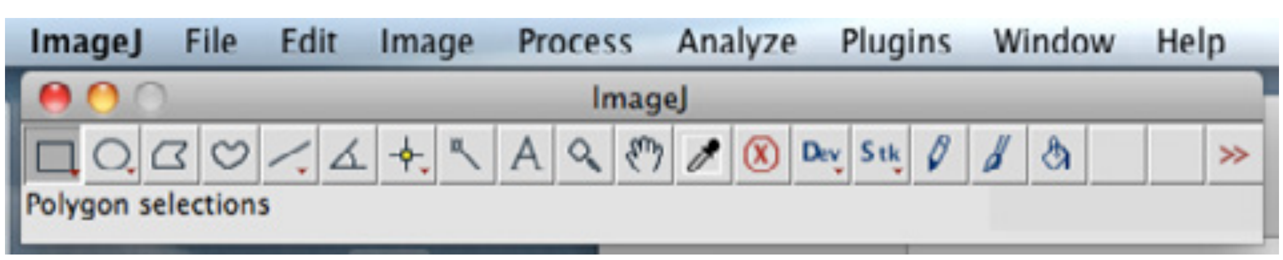
STEP 1. Download free ImageJ software.
STEP 2. Open three bands of Landsat data.
STEP 3. Merge the three bands.
STEP 4. Adjust color balance.
STEP 5. Save the image in TIFF format.

Before you begin, please note:
Landsat scenes are large files. Unzipped Landsat 5 scenes are about 404 megabytes (MB), and Landsat 7 scenes are about 654 MB. This is an important consideration when downloading or manipulating them.

STEP 1. Download free ImageJ software at this URL:

http://rsbweb.nih.gov/ij/download.html

a. Open ImageJ.



b. Increase the memory allocated by your computer to ImageJ.
You need more memory for working with Landsat scenes than the default in ImageJ.
To fix this, go to:
"Edit" > "Options" > "Memory and Threads..."
Adjust the memory up to 1,000 MB. Then quit and restart ImageJ.

STEP 2. Open three bands of Landsat data.

Note: Your choice of bands will depend on whether you want to see just visible light, infrared light, or a combination of visible and infrared.

If you are using Landsat 8 data and want an image in visible wavelengths, open bands 2, 3, and 4. If you are using Landsat 5 or 7 data and want an image in visible wavelengths, open Bands 1, 2, and 3.

Assuming you are using Landsat 8 data and want an image in visible wavelengths:

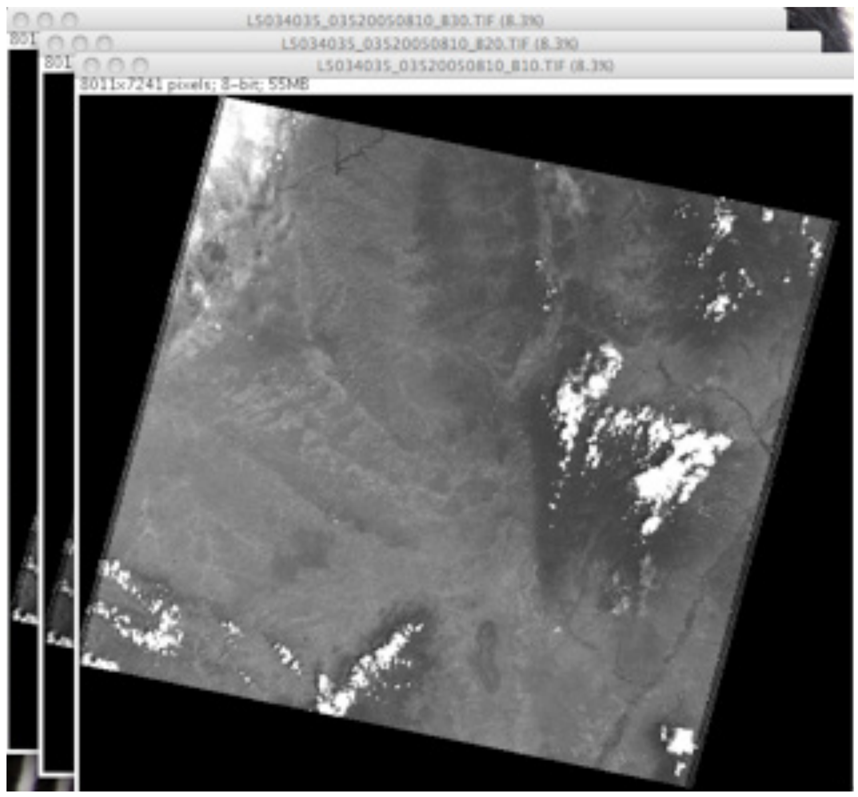
Open Band 2. The file name ends with B2.

Open Band 3. The file name ends with B3.

Open Band 4. The file name ends with B4.

Please note: In this tutorial, "Channel" and "Band" are equivalent terms.

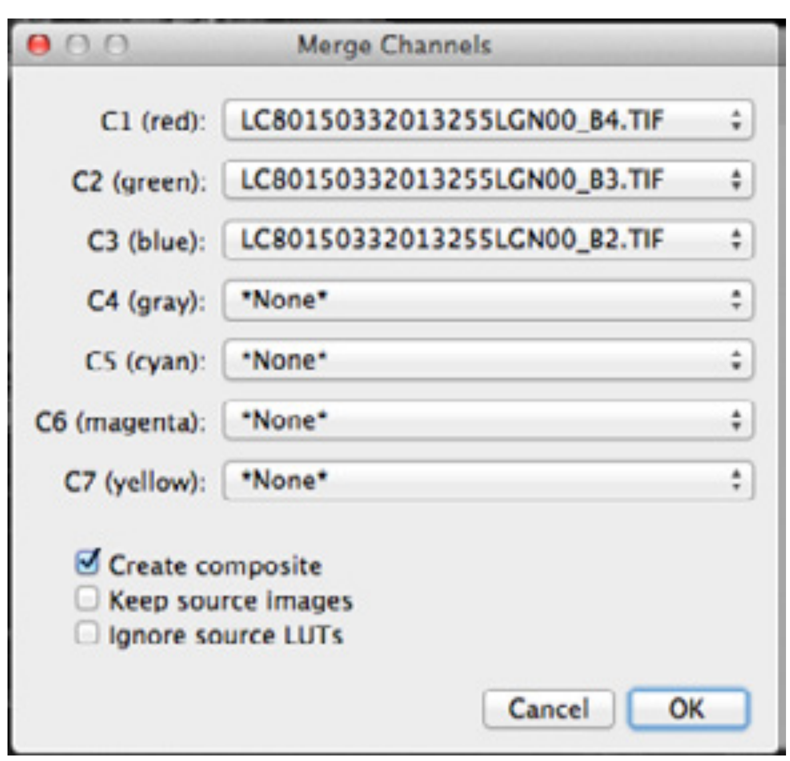
Each of the band images will appear in shades of gray, as in the image below.



STEP 3. Merge the three bands of data.

a. Select "Image" > "Color" > "Merge Channels."

b. Assign Band 4 to the Red channel, band 3 to the green channel, and band 2 to the blue channel.

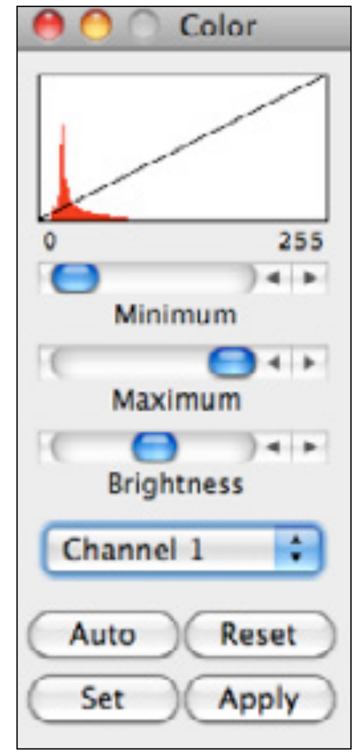


c. Click "OK"

The resulting image ***may not have the colors you expect*** from a visible wavelengths band combination. You will have the opportunity to improve that color in the next step.

STEP 4. Adjust color balance.

a. Go to "Image" > "Adjust" > "Color Balance." A window with a histogram will appear. Notice "Channel 1" in the Color window about one-third of the way from the bottom. ("Channel" and "band" refer to the same thing, for theh purpose of this tutorial.) You will work on Channel 1, then Channel 2, then Channel 3.



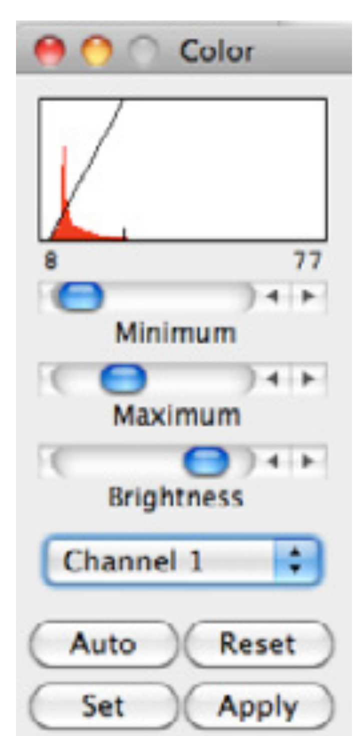
b. With Channel 1 selected, move the slider labeled "Minimum" so that the bottom of the long diagonal line just touches the left edge of the histogram. You can use the left and right arrow keys for greater precision.

c. Move the slider labeled "Maximum" so that the short vertical line that appears when you begin to move the slider to the left, lines up with the right edge of the histogram.

Do NOT click on "Set" or "Apply."

See the image below for an example of how your adjusted color balance for Channel 1 might look.

In the histogram window, the tiny vertical bar at right has been moved to touch the right side of the histogram, and the larger vertical bar at left is touching the left side of the histogram.



d. Change to Channel 2, and repeat the adjustments to the histogram.

e. Change to Channel 3, and repeat.

f. Now click on "Apply."

Keep adjusting the bars on histograms on the three channels (bands) until you have an image with colors that satisfy you. You may want to make several adjustments.

STEP 5. Save the image in TIFF format.

a. Go to "Image" > "Type" > "RBG color."
b. Save the image as a .tiff.

You can stop here with the Landsat 8 "432" band combination, or you can make other images with any combination of Landsat data bands you wish.

You can follow these same steps to make Landsat images in different band combinations.

Useful Band Combinations for Landsat 8:
– Natural Color: 432
– False Color (urban): 764
– Color Infrared (agriculture): 652
– Atmospheric Penetration: 765
– Healthy Vegetation: 562
– Land/Water: 564
– Natural with Atmospheric Removal: 753
– Shortwave Infrared: 754
– Vegetation Analysis: 654

Useful Band Combinations for Landsats 5 and 7:
– Natural Color: 321
– Near Infrared or NIR, or 432
– Short-Wavelength Infrared (SWIR), or 742

To learn more about Landsat scenes, study this tutorial:
Fundamentals of Remote Sensing
http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1430

❖ Going Further with ImageJ

A. **Earth Analysis Techniques** (2011)
http://serc.carleton.edu/earth_analysis/index.html

B. **Eyes in the Sky II** (2009-2010)
http://serc.carleton.edu/eyesinthesky2/

ImageJ tutorials are part of an online resource, Eyes in the Sky II, a professional development program from TERC that includes both online and in-person workshop materials. Educators may find the whole online course useful:
http://serc.carleton.edu/eyesinthesky2/GITcourse/index.html

Parts of it that relate directly to use of ImageJ are these:

A) Introduction to Remote Sensing
http://serc.carleton.edu/eyesinthesky2/week1/remote_sensing.html

B) Week 2: Analyzing Change Over Time / Introduction to ImageJ
http://serc.carleton.edu/eyesinthesky2/week2/index.html

C) Week 11: Using Satellite Data to Investigate Deforestation

Appendix I. Annotated List of Resources

NASA Wavelength
http://nasawavelength.org
Pathway into a digital collection of Earth and space science resources for educators of all levels – from elementary to college, to out-of-school programs.

Landsat at NASA
http://www.nasa.gov/landsat
Features Landsat 7 data characteristics, science and education applications, technical documentation, program policy, and history

Landsat Education
http://landsat.gsfc.nasa.gov/?page_id=11
Rich array of resources for education in formal and informal contexts

Landsat on Facebook
http://www.facebook.com/NASA.Landsat

Landsat on Twitter
http://twitter.com/NASA_Landsat

Flickr Collections of Landsat Images (including shots of satellite being built)
http://www.flickr.com/photos/gsfc/collections/72157629153929192/

Podcast Interviews with Landsat Scientists
http://landsat.gsfc.nasa.gov/?page_id=2331

How People Use Landsat: Case Studies
http://landsat.gsfc.nasa.gov/wp-content/uploads/2013/11/Landsat_Improve_Life1.pdf

Timeline of the Landsat Program and further information
http://landsat.gsfc.nasa.gov/about/timeline.html

Landsat at U.S. Geological Survey (USGS)
http://landsat.usgs.gov/
Features information on the technical aspects of Landsat operations, links to the Landsat 7 data archive, and links to Landsat 7 sample images

USGS Landsat Twitter
http://twitter.com/USGSLandsat

BACKGROUND

Climate Change/Earth Science Week - NASA
http://climate.nasa.gov/eswSite/index.cfm
Spanish Language Version: http://climate.nasa.gov/esw2012espanol/

Earth Observatory
http://earthobservatory.nasa.gov
Freely-accessible satellite imagery, scientific information, and data about our home planet

Interviews with Remote Sensing Scientists on EarthSky Radio

> ***Monitoring Water Use from Space: Martha Anderson:***
http://landsat.gsfc.nasa.gov/news/news-archive/sci_0034.html

> ***First ever image mosaic of entire Antarctica detail: Robert Bindschadler***
http://landsat.gsfc.nasa.gov/news/news-archive/sci_0032.html

> ***Carbon Agreement: Doug Morton***
http://landsat.gsfc.nasa.gov/news/news-archive/news_0319.html

> ***Forest Monitoring: Curtis Woodcock***
http://landsat.gsfc.nasa.gov/news/news-archive/news_0306.html

> ***Tracking changes to Earth's forests from space: Alan Belward***
http://earthsky.org/earth/alan-belward-tracks-changes-to-earths-forests-from-space

Electromagnetic Spectrum - Tour
http://missionscience.nasa.gov/nasascience/ems_full_video.html
Video series including chapters on radio, micro-, infrared, visible, ultraviolet waves; X-Rays; and gamma rays

ACTIVITIES FOR STUDENT LEARNING

Activity Matrix
http://landsat.gsfc.nasa.gov/?p=5186

Quantifying Changes in the Land Over Time
http://landsat.gsfc.nasa.gov/education/resources/Landsat_QuantifyChanges.pdf
Gr. 7-10 students analyze land cover change over time in order to help them grasp the extent, significance, and consequences of change in their regions.

Amelia the Pigeon (Elementary) and Echo the Bat (Middle)
http://imagers.gsfc.nasa.gov/
IMAGERS (Interactive Multimedia Adventures for Grade-school Education using Remote Sensing) project, developed upon a framework that allows for the incorporation of new content, geographic location, and story line using satellite imagery as the foundation

Annotating Change in Satellite Images
http://serc.carleton.edu/eet/measure_sat/index.html
Explanation of a technique for documenting change in before-and-after sets of satellite images. Useful for any set of images that show the same area at the same scale at different times.

Exploring the Environment (Middle & High School)
http://www.cotf.edu/ete/modules/modules.html
Set of remote sensing activities on the Exploring the Environment (ETE) Program

Eyes in the Sky II
http://serc.carleton.edu/eyesinthesky2/index.html
Professional development program created and administered by TERC, Inc. through funding from the NASA K-12 Competitive Grants Program. Provides an introduction to remote sensing and includes tutorials on the use of ImageJ free software through the "GIT Web Course" linked from the homepage.

Integrated Geospatial Education and Technology Training – Learning Unit Exercises
http://igett.delmar.edu/TR_LearningUnits.html
Introductory, intermediate, and advanced exercises created by two-year college instructors of Geographic Information Systems (GSI), through which students download, analyze, and integrate remote sensing data with GIS to solve practical problem

Landsat Image Mosaic Of Antarctica (LIMA)
http://lima.usgs.gov/
The first-ever true-color high-resolution satellite view of the Antarctic continent enabling everyone to see Antarctica as it appears in real life.

Mission Geography
http://missiongeography.org/
Curriculum materials that link the content, skills, and perspectives of Geography for Life: The National Geography Standards with the missions, research, and science of NASA, developed by the Geography Education National Implementation Project (GENIP) at Texas A&M University (K-12)

NASA Wavelength
http://nasawavelength.org/

DATA

USGS Global Visualization Viewer (GloVIS)

http://glovis.usgs.gov/

Website to query and order no-cost Landsat data. (Register and log on first at Earth Explorer: http://earthexplorer.usgs.gov

IMAGES / MOVIES

NASA Wavelength Data and Images

http://nasawavelength.org/data-and-images

Earth as Art

http://eros.usgs.gov/imagegallery/

High resolution images selected for aesthetic qualities only, available to download at no cost

EarthNow! Landsat Image Viewer

http://earthnow.usgs.gov

Near real-time views of Earth from Landsat. Requires user acceptance to Run application.

Flickr Collections of Landsat Images *(including shots of satellite being built)*

http://www.flickr.com/photos/gsfc/collections/72157629153929192/Earth Right Now – 2-min. video

http://www.jpl.nasa.gov/video/?id=1271#fragment-1

Images at Landsat

http://landsat.visibleearth.nasa.gov

Collection of Landsat images from many sources. Data and applications from Landsat 4, 5 and 7 are presented, as well as photographs of the construction and testing of Landsat 7. Links provide useful background information and visualizations of Landsat data.

Landsat Resource Gallery – NASA's Scientific Visualization Studio server

http://svs.gsfc.nasa.gov/Gallery/Landsat.html

Contains links to many videos, animations, and visualizations of Landsat data

Scene Changes

http://www.scenechanges.org/

Landscapes featured in literary works, with discussions on how they have changed and why.

USGS Landsat Image Gallery
http://landsat.usgs.gov/gallery_view.php?category=nocategory&thesort=pictureId
Array of images including Earth features such as volcanoes, floods, and cities

Visualization Explorer
http://svs.gsfc.nasa.gov/nasaviz/index.html

World of Change
http://earthobservatory.nasa.gov/Features/WorldOfChange/
Pairs of images useful for analyzing change over time

INSTRUMENT: Hand-held Spectrometer

ALTA II Reflectance Spectrometer
http://www.vernier.com/products/sensors/spectrometers/alta/

ALTA activities for learning about the moon, has Earth-relevant activities as well
http://www.lpi.usra.edu/education/workshops/unknownMoon/Monday/M3EducatorGuide1.pdf

SOFTWARE and TUTORIALS

Fundamentals of Remote Sensing
http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1430
The Canada Centre for Remote Sensing offers this tutorial on remote sensing technology and its applications, for senior high school or early university level and touches on physics, environmental sciences, mathematics, computer sciences and geography.

The GLOBE Program, Land Cover/Biology Chapter of the Teacher's Guide
http://www.globe.gov
Global Learning and Observations to Benefit the Environment (GLOBE) is a hands-on international environmental science and education program.

ImageJ
http://rsbweb.nih.gov/ij/
Free public domain image processing software developed at the National Institutes of Health. Use ImageJ to display, annotate, edit, calibrate, measure, analyze, process, print, and save raster (row and column) image data. ImageJ User Guide:
http://rsbweb.nih.gov/ij/docs/user-guide.pdf

MultiSpec™
http://cobweb.ecn.purdue.edu/~biehl/MultiSpec/
Free software developed at Purdue University

SCIENCE BACKGROUND

NASA's Earth Observatory
http://earthobservatory.nasa.gov
Freely-accessible satellite imagery, scientific information, and data about our home planet.

Tour of the Electromagnetic Spectrum
http://missionscience.nasa.gov/nasascience/ems
Video series including chapters on radio, micro-, infrared, visible, ultraviolet waves; X-Rays; and gamma rays

Thermal Radiation and the Electromagnetic Spectrum
http://svs.gsfc.nasa.gov/vis/a010000/a011000/a011005/index.html

Analyzing Land Use Change in Urban Environments
http://landcover.usgs.gov/urban/info/factsht.pdf

Changing Global Land Surface
http://earthobservatory.nasa.gov/Library/LandSurface/

A Guide to Land-Use and Land-Cover Change (LU/LCC)
(Includes LU/LCC and the Hydrological Cycle, LU/LCC and Climate Change; and LU/LCC and Urbanization)
http://sedac.ciesin.columbia.edu/tg/guide frame.jsp?rd=LU&ds=1
Foley, et al., 2005. "Global Consequences of Land Use." Science Vol. 309, 22 July 2005, pp. 570-574 (www.sciencemag.org)

Land Cover Classification
http://earthobservatory.nasa.gov/Library/LandCover/

Urban Heat Island: Atlanta, Georgia
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img id=17489

Resources on CAREERS that Use Remote Sensing, Geographic Information Systems (GIS), and Other Geospatial Technologies

American Society for Photogrammetry and Remote Sensing career brochure
http://www.asprs.org/career

GIS Jobs, GISP Certification, and Geospatial Careers - By Directions Magazine
http://www.directionsmag.com/images/ebooks/2013/07/GIS-jobs.pdf

Geospatial Revolution
http://geospatialrevolution.psu.edu
Series of videos demonstrating the benefits and dramatic changes to society with the use of geospatial technologies such as Geographic Information Systems and remote sensing data

Professional Geospatial Associations:
- American Congress on Surveying and Mapping (ACSM)
- American Society of Photogrammetry and Remote Sensing (ASPRS)
- Association of American Geographers (AAG)
- Geospatial Information and Technology Association (GITA)
- Urban and Regional Information Systems Association (URISA)
- GIS Certification Institute (GISCI)
- Management Association for Private Photogrammetric Surveyors (MAPPS)
- National States Geographic Information Council (NSGIC)
- University Consortium for Geographic Information Science (UCGIS)

U.S. Department of Labor
http://online.onetcenter.org/
See "Occupational Search" at right, search on "remote sensing."

The spatial resolution of Landsat is 30 meters (98.5 feet). This means that each pixel in a Landsat image represents an area on Earth's surface that is 30m X 30m (roughly 90 feet by 90 feet).

Spectral Resolution
Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as multi-spectral sensors and will be described in some detail in following sections. Advanced multi-spectral sensors called hyperspectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands. (Canada Centre for Remote Sensing Tutorial, Fundamentals of Remote Sensing)

Appendix II. Background on Our Changing Landscapes

- ❖ **What are "land cover" and "land use?"**
- ❖ **Why do we study land cover change?**

What are "land cover" and "land use?"

People who spend much of their time looking at data on the Earth from space find certain terms useful. For example we can call anything at the surface of the Earth "land cover." Whether they are lakes, fields, city streets, buildings, gardens, bridges or roadways, mountains, forests, or glaciers, all that we see at the surface can be understood and spoken about as land cover.

The terms land cover and land use are closely related. What people do with land cover is land use. For example some land is used for transportation (such as for roads, railways, airports, parking lots, or sidewalks). Some land is used for farming. Some land is used for housing and some for recreation (such as for ski areas, campgrounds, hiking and biking tails, boating areas). Some land is for industry (such as mining). Some land is set aside to protect wildlife.

The term land cover change refers to any change that occurs to the land cover at any time. Some changes occur slowly and some occur quickly. Streams take thousands to millions of years to develop. Mountains take millions of years to rise, and more time to weather and erode. Deposits of the sediments created from weathering and erosion also take a very long time to form completely. Rapid changes include volcanic eruptions, hurricanes, forest fires, and tsunamis. An example of short-term change caused by people is the growth of cities.

Some changes are beneficial, and some can be damaging to the balance of sustainability in the natural environment, causing problems for people and ecosystems.

Why do we study land cover and land cover change?

From space we can see that land once covered by forest is being changed into farmland; land covered by farmland is becoming suburbs; urban areas are growing; shorelines are shifting; glaciers are melting; and ecosystem boundaries are moving. More than 50 percent of the world's human population now lives in areas of contiguous urban development. We are driving landscape-scale changes on our planet.

People change the land surface, vegetation, water cycle, radiant heat, and other aspects of the landscape. These changes allow the human populations to grow, but they also affect the ability of the land to produce food, maintain fresh water and healthy forests, regulate climate and air quality, and provide other essential services.

It is critical for our survival and well-being that we understand the changes we are bringing about to Earth's systems, and the consequences of our actions on the planet's ability to support life as we know it.

The first step in understanding change is monitoring; the second is analysis. This Training Toolbox will assist educators in working with others to take those two steps.

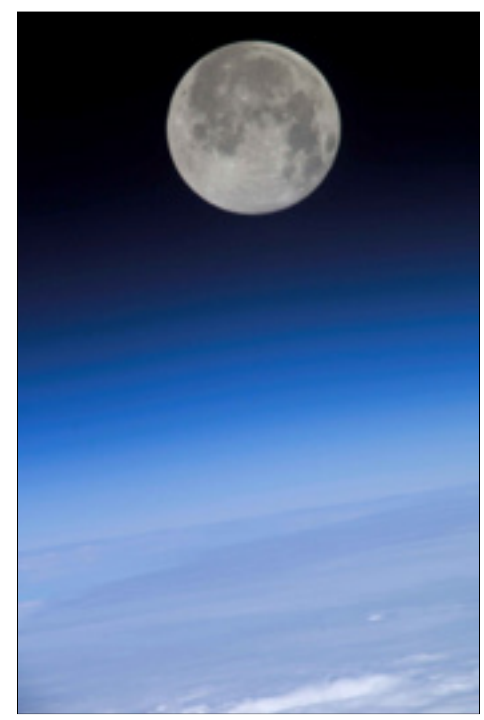
Appendix III. Background on Remote Sensing with Landsat

- What Are Satellites?
- Gravity, Velocity and Orbits
- What is Remote Sensing?
- Landsat Satellites and Their Instruments (Sensors)
- The Electromagnetic Spectrum
- Spectral Bands
- Colors of Light versus Colors of Pigment
- True Color versus False Color Imaging
- Pixels, Bands, and Images

What are satellites?

Satellites are objects that orbit other objects. The Earth's Moon orbits the Earth and so is a satellite, and the Earth itself is a satellite of the Sun. Artificial (human-made) satellites such as Landsat are machines that we place in orbit around the Earth, the Sun, or another body in space.

Human-made satellites carry sensitive instruments that scientists and engineers develop with enormous care. What the instruments are designed to detect depends on the specific questions scientists are asking. For example, if scientists are trying to find out how much heat is being emitted from a city, they can use a sensor that detects far-infrared wavelengths of the electromagnetic spectrum.



The Earth's Moon orbits the Earth and so is a satellite.

Landsat Uses a Passive Sensor

Active sensors send some kind of radiation, such as laser, microwaves, or radar, at areas or objects of interest to make measurements. Passive sensors do not send any radiation, but measure radiation reflected by the target. Landsat uses passive sensors, as it observes primarily reflected radiation (and secondarily, some emitted, thermal radiation). An example of a NASA mission using active sensors is the Gravity Recovery and Climate Experiment (GRACE) (http://www.csr.utexas.edu/grace/), which uses microwaves.

Gravity, velocity and orbits

The Satellite's Path

Putting a satellite into orbit requires understanding certain laws of energy and motion. Newton's first law of motion recognizes that objects with velocity tend to keep that velocity unless acted upon by an outside force. When a satellite is put into orbit, it is given a high velocity in a direction that we can think of as horizontal.

Assume you are under the satellite looking up when the satellite has launched and the launch rockets have shut down. Now the satellite is coasting, and it has horizontal velocity. Since there is very little atmospheric resistance, the satellite will keep that horizontal velocity. (Newton wrote this, and he knew what he was writing about!) Pretend end there is no gravity for a moment. In that case the satellite would just continue in a straight line, leave our solar system and continue to move outward into the rest of the galaxy. (Remember that straight line, because we will refer to it again.)

However, the satellite is still being acted upon by Earth's gravity (as well as the velocity it got from launch), so it starts falling toward Earth. It has its original horizontal velocity, and because of gravity, it develops some vertical velocity. The direction of its path bends toward the Earth as it moves horizontally. It is in orbit.

As the launched satellite travels, and as its path has bent away from the straight line of its launch due to gravity, the Earth's surface also curves away in the same direction as the bend in the satellite's path. The path of the satellite continues to bend further from that straight line, and the Earth's surface continues to curve away. As the path bends, gravity continues acting in a direction perpendicular to the curve of the orbit. If the original horizontal velocity (launch of the rocket propelling the satellite) is the right magnitude, the bending of the satellite's path and the curve of the Earth's surface will be almost parallel. We will have the desired orbit.

The higher a satellite's orbiting altitude, the longer it takes to complete an orbit.

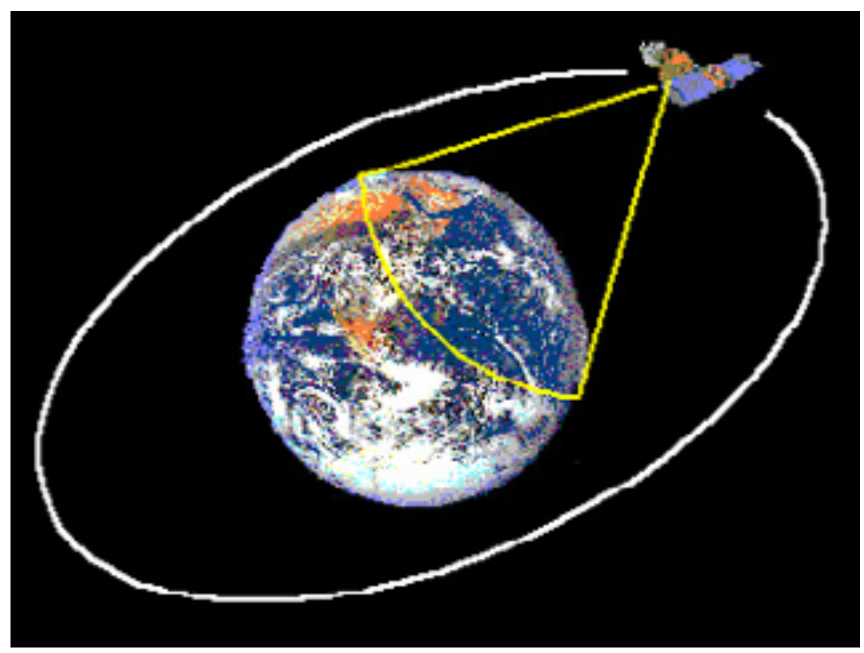
Rocket scientists have to understand how much fuel and what kind to use in order to propel a spacecraft of a given weight into the desired orbit. If they make a mistake, a satellite worth millions of dollars can be lost.

Types of Orbits

Satellites can operate in several types of orbits. The most common orbits for environmental satellites are geostationary and polar orbits.

In geostationary orbits, the satellite is always in the same position with respect to the rotating Earth. It travels at the same rate and in the same direction as the Earth rotates. The satellite orbits at an altitude of approximately 35,790 km because that altitude produces an orbit time equal to the period of rotation of the Earth: 23 hr., 56 min., 4.09 sec.

Geostationary satellites are used to observe the weather, and are particularly helpful for helping forecasters to warn us about severe storms and tropical cyclones.



A satellite in geostationary orbit appears stationary with respect to the Earth's surface, partly because its altitude enables it to orbit the Earth once every 23 hr., 56 min., 4.09 sec., the period of the Earth's rotation. Credit: National University of Singapore, Center for Remote Imaging, Processing, and Analyzing

Polar-orbiting satellites travel around the Earth from pole to pole, at a near-polar inclination while the Earth rotates under them. (A true polar orbit has an inclination of 90 degrees.) This orbit enables a satellite to observe all regions of the Earth over time.

Landsat satellites operate in near-polar orbits at an average altitude of 705 km (438 miles) at the Equator. Circling the Earth at 7.5 km/sec, the satellites complete one orbit in nearly 99 minutes. They complete just over 14 orbits per day, covering the entire Earth between 81 degrees north and south latitude every 16 days. Since two Landsat satellites – numbers 5 and 7 -- are orbiting the Earth as this Guide is written, a Landsat satellite flies above each location on Earth every eight days.

Following the Sunlight

As explained above, the sensors onboard Landsat satellites observe light that is reflected from the Earth's surface. In order to see Earth's surface, they must follow where sunlight hits it. In other words they must pass over a given location at essentially the same solar time throughout all seasons of the year.

This sun-synchronous orbit enables data collection at consistent times, avoids different angles of sunlight, and so facilitates comparing Landsat scenes from one time to another. Without it, changing shadow positions and other lighting conditions would make such comparisons difficult.

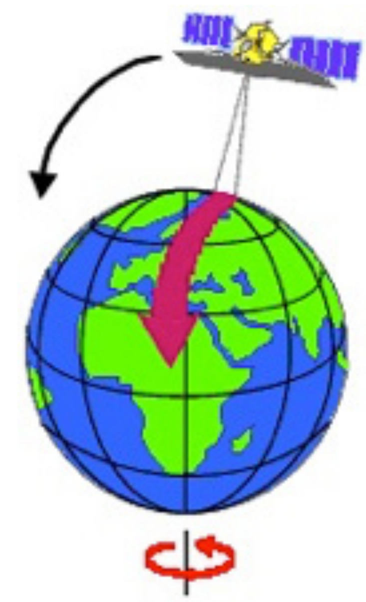


Diagram courtesy of NASA

On the right is an example of a swath, or the amount of land observed as a satellite passes over Earth. Note the red arrow under Earth, which illustrates the direction the Earth is rotating underneath the satellite.

A useful lesson about satellite orbits can be found at the American Association of Applied Sciences website at http://www.sciencenetlinks.com/lessons.php?DocID=338.

Landsat Satellites and Their Instruments

What Is Landsat?

Landsat is a series of Earth-observing satellite missions now jointly managed by NASA and the U.S. Geological Survey. Since 1972, Landsat satellites have taken specialized digital datasets (scenes) of Earth's continents and surrounding coastal regions, enabling people to study many aspects of our planet and to evaluate the dynamic changes caused by both natural processes and human practices.

Landsat provides essential maps for understanding and caring for the places we live and work. The duration, quality, and consistency of Landsat observations enable professional and student investigations of local, regional, and global changes in the land and their communities over time. Pixel by pixel, Landsat has been consistently gathering data about our planet, recording the entire global land surface, every season, every year. The science and technology of remote sensing have matured with the Landsat Program.

Pixel by pixel, Landsat has been consistently gathering data about our planet, recording the entire global land surface, every season, every year.

Landsat 7 has been in orbit since 1999. Landsat 8 launched in February 2013, improving and expanding an unparalleled record of Earth's changing landscapes for everyone's benefit.

Landsat Scenes and Pixels

As the spacecraft moves along its path, the sensor scans the terrain below.
Each Landsat scene covers an area 185 km by 172 km (115 mi by 107 mi). A grid system of paths and rows is used to provide a reference number for each scene. Each path and row grid can also be identified by its latitude and longitude.

Spatial resolution is the size of a single picture element, or pixel, in the satellite's image. Spatial resolution describes how close two features can be within an image and still be viewed separately. A picture element, or pixel, is a single point in a graphic image. Images are made up of thousands or millions of pixels.

Computers display pictures by dividing the dis¬play screen into thousands (or millions) of pixels, arranged in rows and columns. The pixels are so close together that they appear connected––the same is true of a satellite image. If you look at a computer monitor with a magnifying lens, you can see the individual pixels. If you zoom in close enough on a satellite image you can also see the pixels.

The squares you see are the dots or pixels (short for picture elements) that make up the image. An important concept is that — despite the impression given by those amazing FBI image processing techs you see in movies and television — you can't zoom in to an image indefinitely. When you reach the point where you can distinguish the individual pixels, you won't see additional details by zooming in more. (Eyes in the Sky II)

The spatial resolution of Landsat is 30 meters (98.5 feet). This means that each pixel in a Landsat image represents an area on Earth's surface that is 30m X 30m (roughly 90 feet by 90 feet).

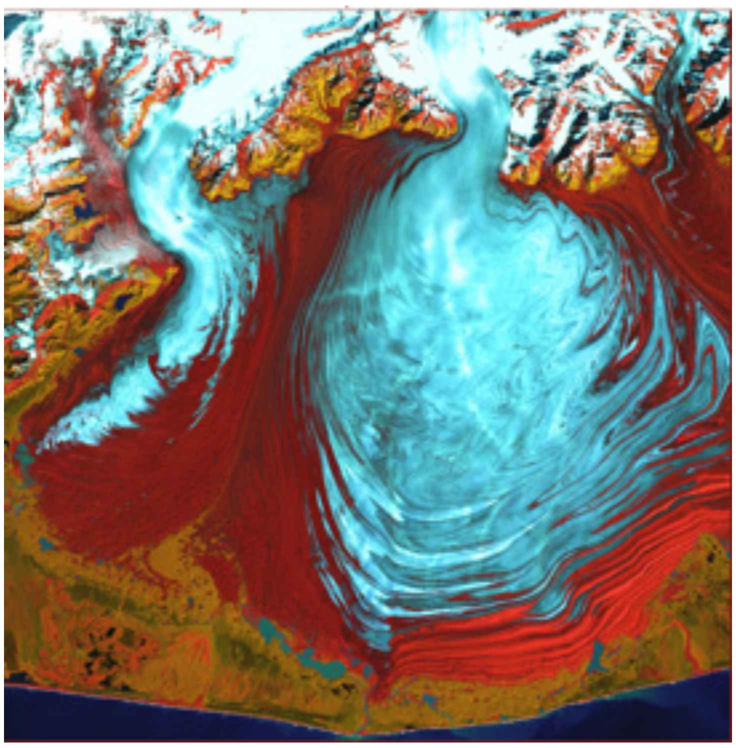
Spectral Resolution

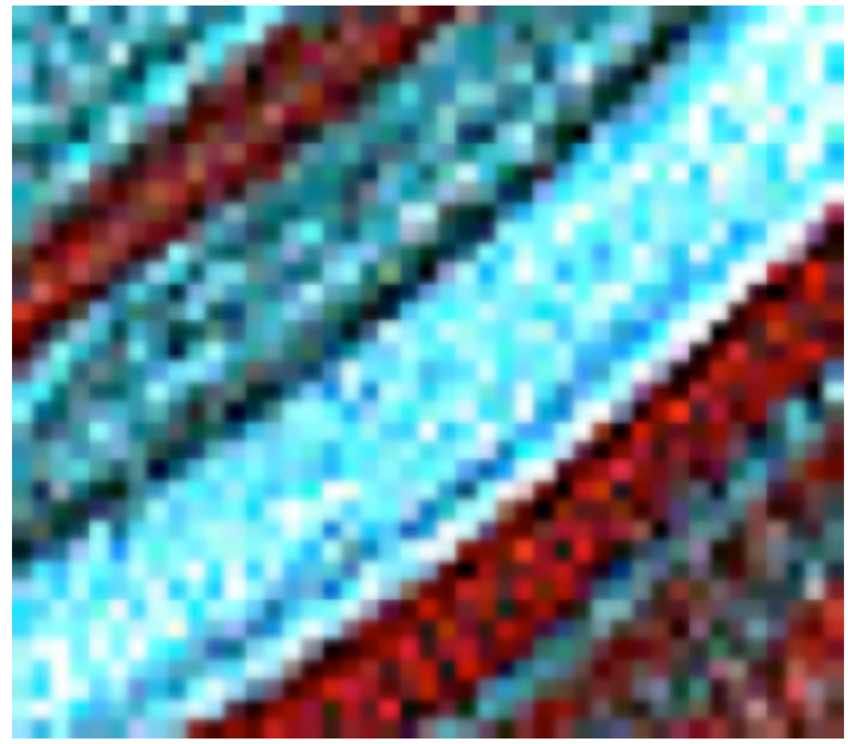
Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as multi-spectral sensors and will be described in some detail in following sections. Advanced multi-spectral sensors called hyperspectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands. (Canada Centre for Remote Sensing Tutorial, Fundamentals of Remote Sensing)

Pixels, Bits, and Images

A Landsat image is made up of individual picture elements, or pixels, arranged in a grid of rows and columns. Usually when we look at an image the individual pixels are too small for us to see. Zooming into the image allows us to see them.





The false color image at left shows the Lena River Delta in Siberia. By zooming in far enough on an image, you can see its pixels. The image at right shows the small rectangles of individual picture elements, or pixels, that make up a tiny portion of the whole image.

The Electromagnetic Spectrum (EMS)

Introduction to the EMS

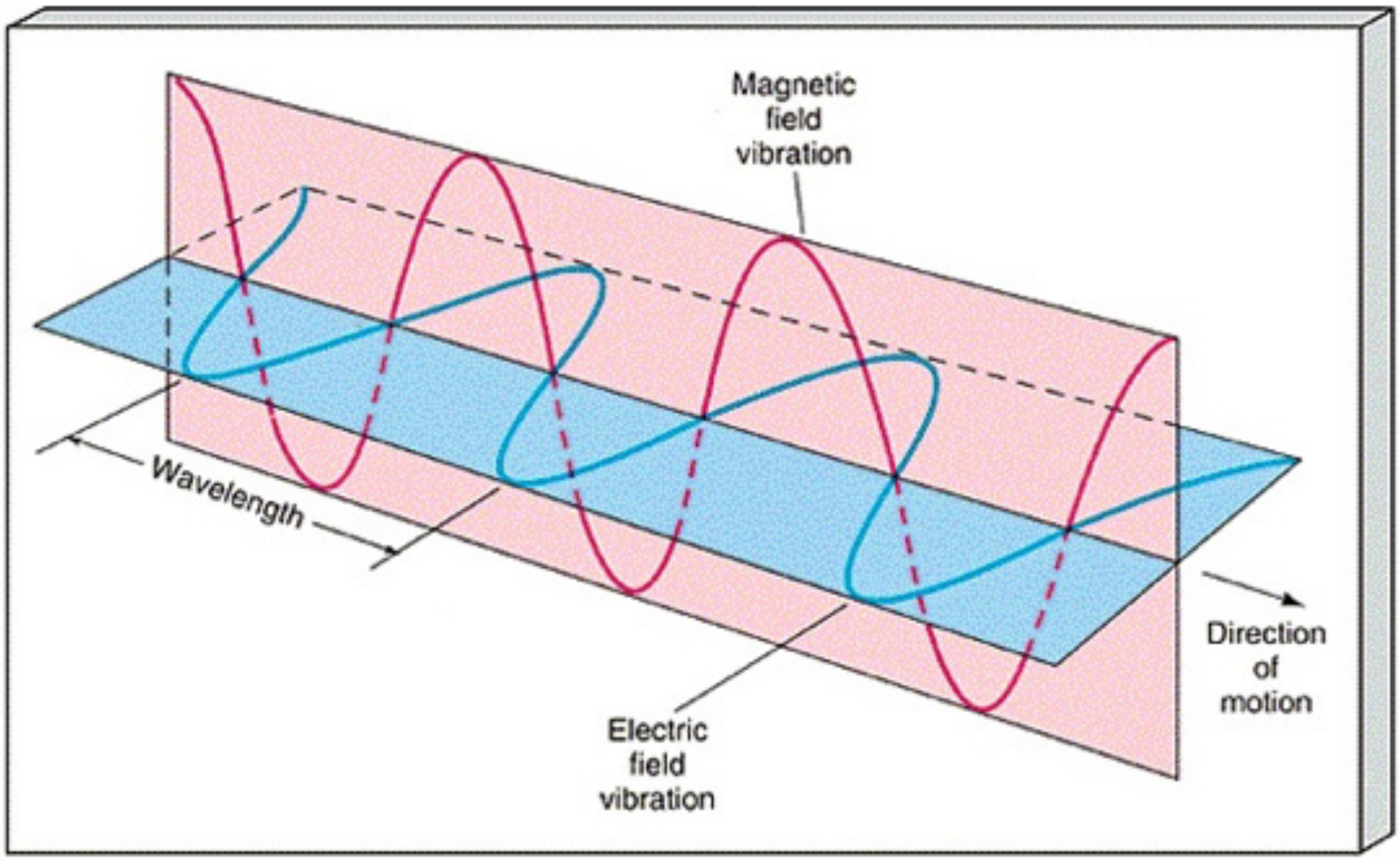
An excellent set of videos to introduce learners to the electromagnetic spectrum can be viewed or downloaded at this URL:
http://missionscience.nasa.gov/nasascience/ems_intro.html

Electromagnetism is more familiar to you than you might think. It's all around us and is essential to our world. People, trees, air, tables, cars, the Sun, the Earth, and all the stars and planets are constantly reflecting and emitting a wide range of electromagnetic radiation. Without it we would have no life. Aside from its critical role of providing the energy for us to keep warm and for plants to grow, we use it to heat our food, carry cell phone calls, and even bring music to our radios.

Electromagnetism occurs because an accelerating electrical charge creates a magnetic field. Electromagnetic energy radiates in every direction from its source.

The interacting electric and magnetic fields involved in producing electromagnetic radiation operate at right angles (perpendicular) to one another and to the direction the energy is moving, as represented in the illustration below. As one type of energy is moving up and down, the other is moving from side to side.

Electromagnetic waves travel through the vacuum of space at the constant speed of light, 300,000 km per second (186,000 mi per sec).



This figure illustrates the motion of the electrical field (in blue) relative to the magnetic field (pink), and the directions the energy is moving. The movement of the electrical charges (energy) produces the magnetic field creating the ***electromagnetic spectrum****.*

Electromagnetic radiation has what may appear to us as a dual personality. It acts as both a series of waves and a as stream of particles (photons). Photons have no mass. They do have energy!

Photons with the highest energy (gamma rays) correspond to the shortest wavelengths of electromagnetic radiation, and photons with the lowest energy (radio waves) correspond to the longest wavelengths.

The electromagnetic spectrum (EMS) is the entire range of wavelengths and frequencies of electromagnetic radiation (energy) from the shortest wavelengths (gamma rays) to the longest wavelengths (radio waves). People have given names to different sections of the EMS. We talk about radio, microwave, infrared, visible, ultraviolet, X-ray and gamma rays, gooing from longer to shorter wavelengths. The wavelengths of energy that humans can see are a tiny fraction of the entire range of energy in the whole spectrum.

To learn more about the EMS, see Appendix III, Background on Remote Sensing with Landsat.

Spectral bands

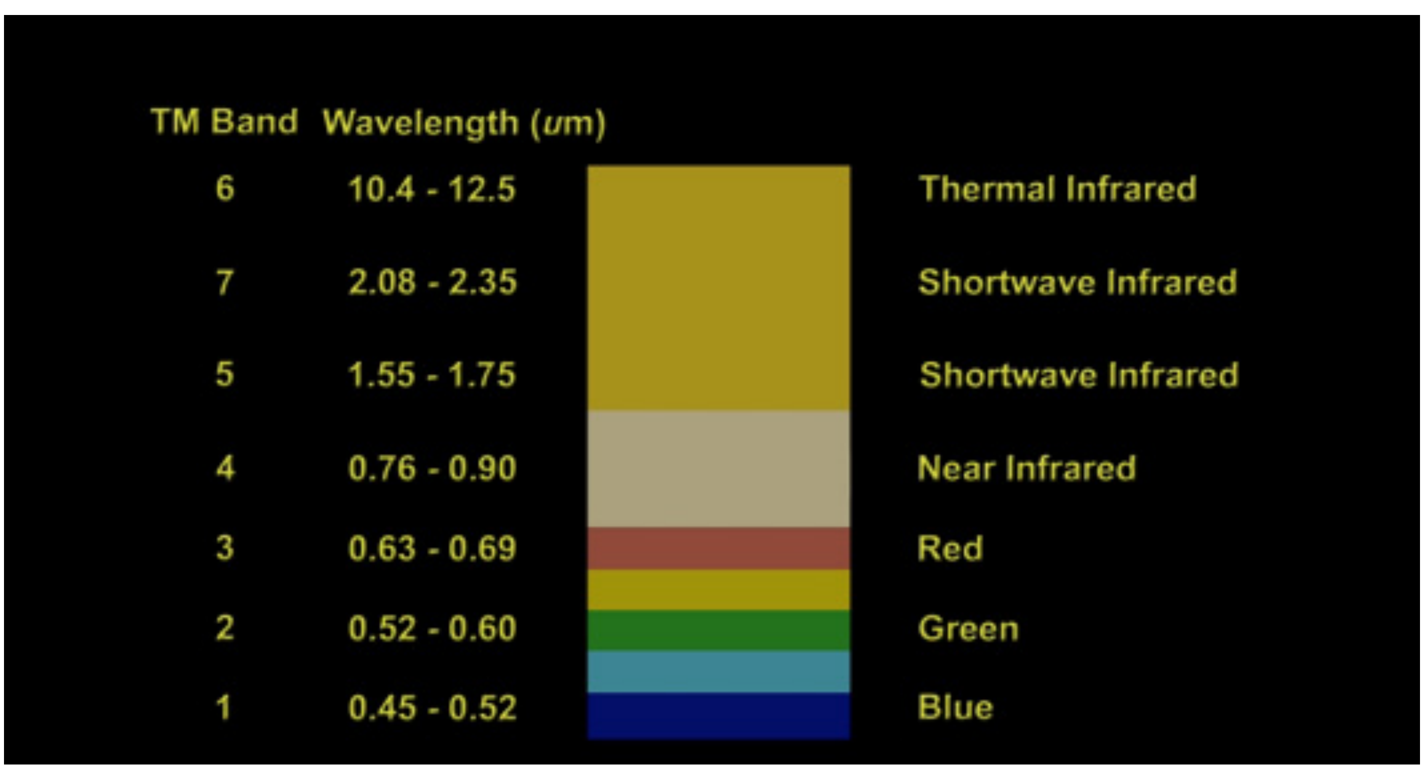
A band of the EMS is simply a range of wavelengths that has been identified for use by remote sensing specialists because of the ways it interacts with and illuminates specific objects of interest. We can program instruments to detect specific wavelength ranges or bands. Our choices of bands will depend on the kinds of information about Earth's surface that we are trying to get.

For example Landsat sensors detect visible wavelengths (red, green, and blue), and near-, mid-, and far-infrared wavelengths. Those are best wavelengths for observing most aspects of land use and land cover change (for distinguishing vegetation from pavement, for example). You can look at the EMS diagram above and compare it with the chart below to identify where each of these wavelength ranges appears in visualizations of the EMS.

Landsat 7 Bands in microns (millionths of a meter or micrometers, μm)

1	0.45-0.52 μm	Blue-Green
2	0.52-0.60 μm	Green
3	0.63-0.69 μm	Red
4	0.76-0.90 μm	Near-infrared
5	1.55-1.75 μm	Mid-infrared
7	2.08-2.35 μm	Mid-infrared
6	10.40-12.50 μm	Far-infrared (thermal infrared)

You may find it peculiar that Band 6 appears after Band 7 in this list. That sequence is purely a factor of the special way in which the Landsat engineers and scientists designed the system.



Landsat 5 and 7 scientists and engineers chose seven wavelength ranges for the sensors to use, and assigned band numbers to them. The ranges of each band are indicated here in microns (millions of a meter), abbreviated as μm.

Notice too that not all the possible wavelengths have been targeted for detection by the designers of Landsat's sensor. In the visible range, for example, the wavelengths between 0.60 and 0.63 are not employed, because it was determined that they were not needed for Landsat's primary mission, looking at land cover and land use change.

Uses of Landsat 7 Spectral Bands

Band 1: 0.45 - 0.52 µm (Blue). Mapping coastal waters, differentiating between soil and plants, classifying forests, and identifying manmade objects such as roads and buildings

Band 2: 0.52 - 0.60 µm (Green). Spans the region between the blue and red chlorophyll absorption bands, so shows the green reflectance of healthy vegetation. Useful for differentiating between types of plants, determining the health of plants, and identifying manmade objects

Band 3: 0.63 - 0.69 µm (Red). One of the most important bands for discriminating among different kinds of vegetation. Also useful for mapping boundaries of soil types and geological formations.

Band 4: 0.76 - 0.90 µm (Near infrared). Especially responsive to the amount of vegetation biomass present in a scene, so useful for crop identification, for distinguishing between crops and soil, and for seeing the boundaries of bodies of water

Band 5: 1.55 - 1.75 µm (Mid-Infrared). Sensitive to the amount of water in plants (turgidity), so useful for studies of drought and plant vigor. Also useful for discriminating among clouds, snow, and ice

Band 6: 10.4 - 12.5 µm (Thermal infrared). Measures the amount of heat (part of infrared radiation) emitted from surfaces, so helps to locate geothermal activity, classify vegetation, and analyze vegetation stress

Band 7: 2.08 - 2.35 µm (Mid-infrared). Particularly helpful for discriminating among types of rock formations and for observing vegetation moisture content

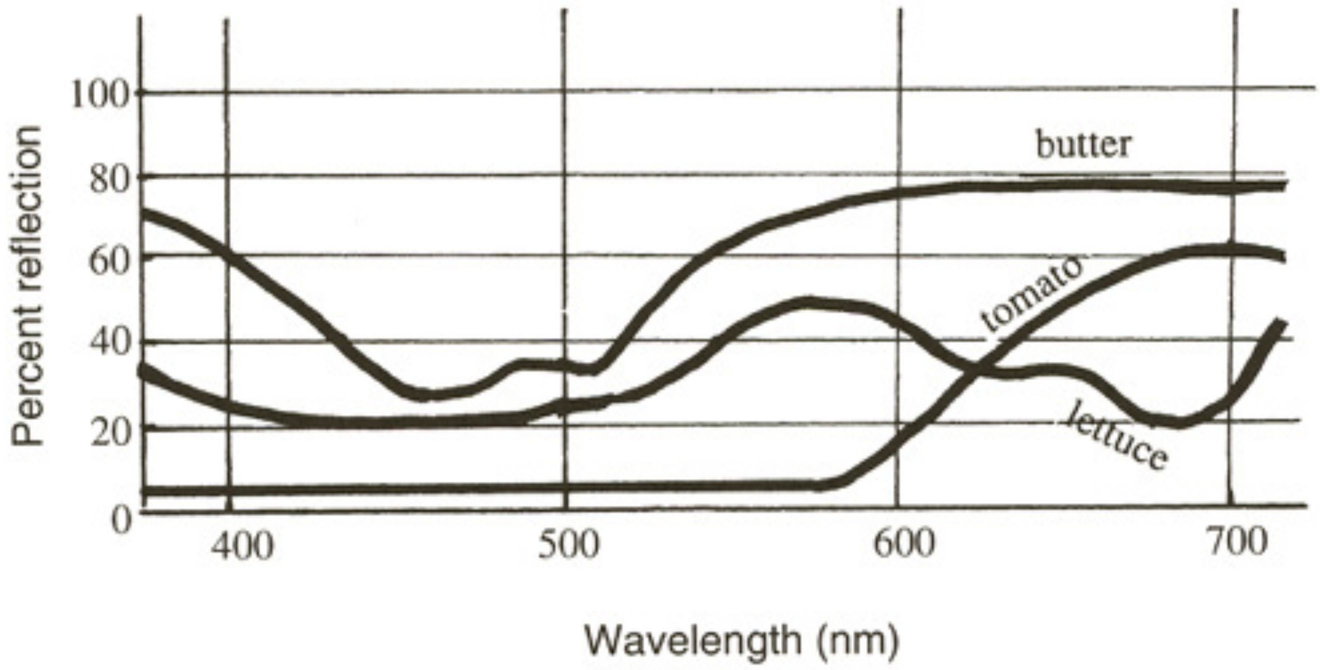
Light Strikes the Target

When light from the sun strikes a target such as the Earth's surface, it is absorbed, reflected, scattered, or absorbed and re-emitted as heat. Landsat sensors have been designed to observe primarily the light that is reflected from Earth (and secondarily some that is emitted).

Core Concept: for any given material, the amount of reflected and emitted radiation varies by wavelength. In other words, every kind of surface reflects light a little bit differently from every other kind of surface, according to which wavelengths it absorbs and which wavelengths it reflects, and by how much.

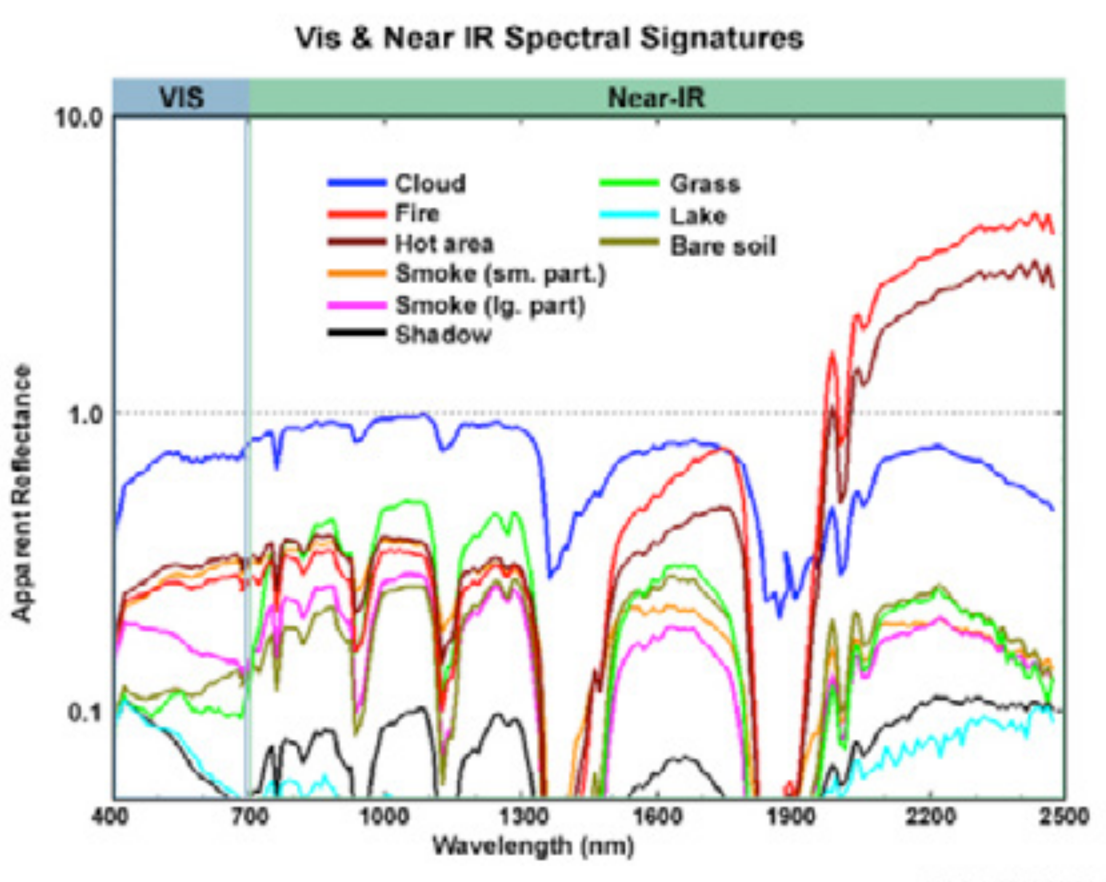
The response of any given surface can be graphed according to its responses to the different wavelengths of light. A graphed plot of all of a surface's response to light produces a unique line, or spectral signature. Spectral signatures are characteristic of specific kinds of surfaces, and people use them to identify surfaces in remote sensing data.

Different sets of spectral signatures appear in the two graphs below. Each line in each graph represents a spectral signature.



Butter reflects weakly between about 450 and 525 nm, and strongly between 525 and 700 nm. Tomato reflects weakly between 400 and 580 nm, and strongly between about 630 and 700 nm. Lettuce reflects rather weakly between 400 and 530 nm, and more strongly at about 575 nm and about 715 nm.

The spectral signatures of clouds, fire, hot areas, smoke, shadow, grass, lake, and bare soil appear in the illustration below.



Fire fighters would find this set of spectral signatures useful. Clouds clearly reflect more strongly than the other surfaces do. The spectral signatures of fire itself, hot areas, and smoke tend to resemble one another, but they can be distinguished! Indeed fire fighters do use remote sensing, particularly after a fire to identify the areas that have been burned the most, and so are in greatest need of restoration.

Core Concept: Now you can understand that *different kinds of land cover have different spectral signatures.* That is why using Landsat we can identify different kinds of land cover and its changes over time.

As you look at the graphs of spectral signatures, you can also understand that there is a specific *numerical value* for the amount of reflected light at each wavelength.

In Landsat's case the sensor has been designed to register the values of reflected light on a scale of *0 to 255*. That number indicates the amount of light reflected from the land's surface to the sensor in a given wavelength range. 0 indicates that no light is reflected at that wavelength range; 255 indicates that a lot of light is reflected at that wavelength range. Using a scale of 0-255 gives us 256 degrees of intensity.

There is a story behind the number 256. The story starts with the fact that Landsat data come to the sensor in a continuous stream. The stream of data has to be divided into chunks or bits (quantized) so we manage it. When the Landsat 7 sensor and data management system were designed, it was decided there would be eight bits, meaning that the data stream would be divided by 28, which equals 256.

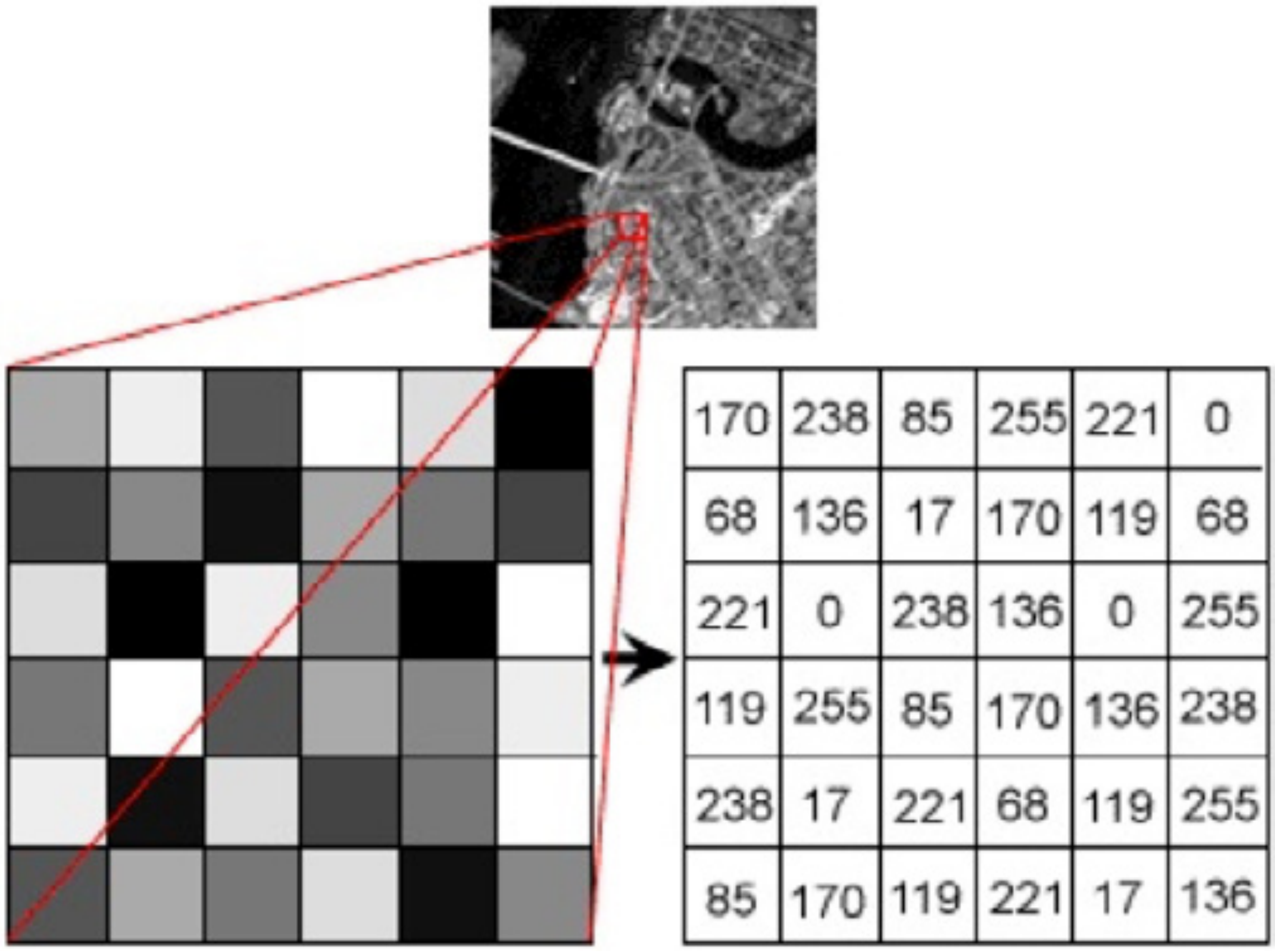
The data system on the next Landsat mission (Landsat Data Continuity Mission, or Landsat 8) has a higher quantization of the data: 12-bit quantization, or 212 . This means that instead of having 256 intensity values, we will have 4,096 intensity values. That's a much finer degree of chunking the data and will show finer details.

Remember pixels? If so, you will recall that Landsat pixels represent areas 30 m x 30 m areas on the ground. *For each pixel*, the sensor observes the amount of reflected light *for each of Landsat's seven wavelength ranges*.

Given that reflectance values may differ from one side of a 30 m pixel to another, the sensor has to average the reflectance value within each pixel. So the number between 0 and 255 which we get for each wavelength range on each pixel represents an amount of reflected light that has been averaged across the 30 m x 30 m area.

Thus for each pixel we have seven numbers: one number for each Landsat band or wavelength range – red, green blue, short-wave infrared, mid-infrared (two of those) and thermal infrared.

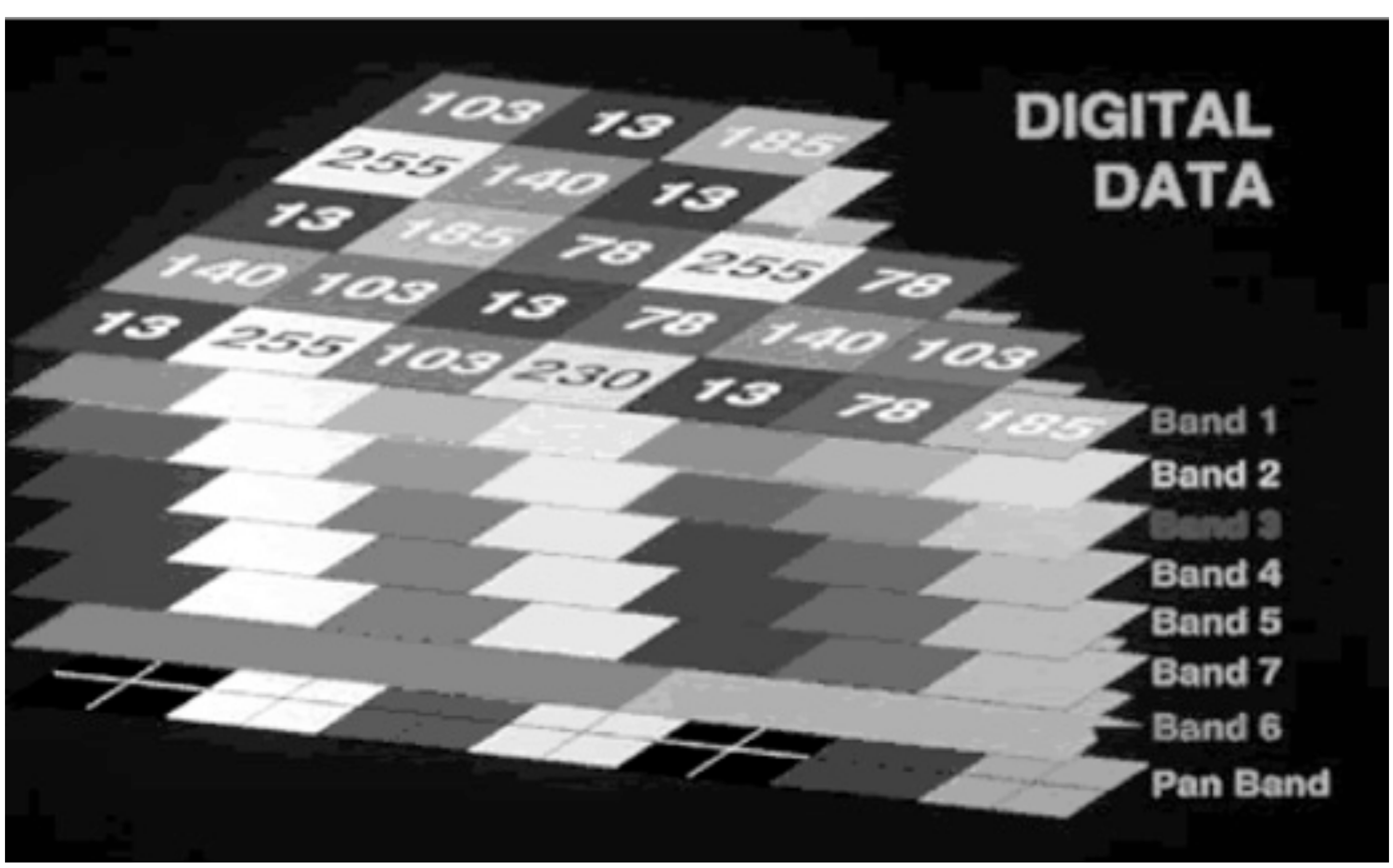
Now consider lots of pixels together. The image below represents Landsat's record of an area covered by 36 pixels on the ground in only ONE wavelength range or band. This image provides a helpful way of understanding how the sensor works. Use this illustration to help you grasp the idea of numerical values representing the amounts of light reflected from each 30m x 30m square on the ground.



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

For each pixel, Landsat records the amount of reflected radiation on a scale of 0 to 255. 0 indicates that no light in a given wavelength range has been reflected; it has all been absorbed. 255 indicates that all light in a given wavelength range has been reflected. By far most pixels will reflect in amounts somewhere between those two numbers.

Now consider a representation of all seven wavelength ranges plus the pan band, together.



Note the wavelength intensity values from 0-255 in the band layers above. (Only the top band layer shows numbers, but in fact each of the pixels in each band layer will have single value ranging from 0-255.) Each number indicates an amount of reflected light in a specific wavelength range for a 30m x 30m area on Earth's surface.

That's a lot of data, by the way. When you think about how many 30 m x 30 m squares comprise Earth's surface, and how many years Landsat has been making observations, you may get some sense of the amount of data we now have. Consider the challenge facing the U.S. Geological Survey (USGS) whose job it is to download, organize, store, and disseminate Landsat data to the people who want it, day after day!

Pause, Consider, and Reflect: What we have now is a series of numbers that represent reflectance values for each pixel in a Landsat scene. How can we make an image from those numbers, so we can perceive them in a way our brains can see best, and understand more clearly what they mean?

Making an Image with Landsat 7

People can see only the wavelengths for red, green, and blue. We cannot see wavelengths longer or shorter than that, such as infrared (longer) or ultraviolet (shorter) wavelengths. We create Landsat images that show infrared wavelengths by assigning visible colors to them in computer software. We can make images that show just visible wavelengths, or a combination of visible and infrared wavelengths, or just infrared wavelengths.

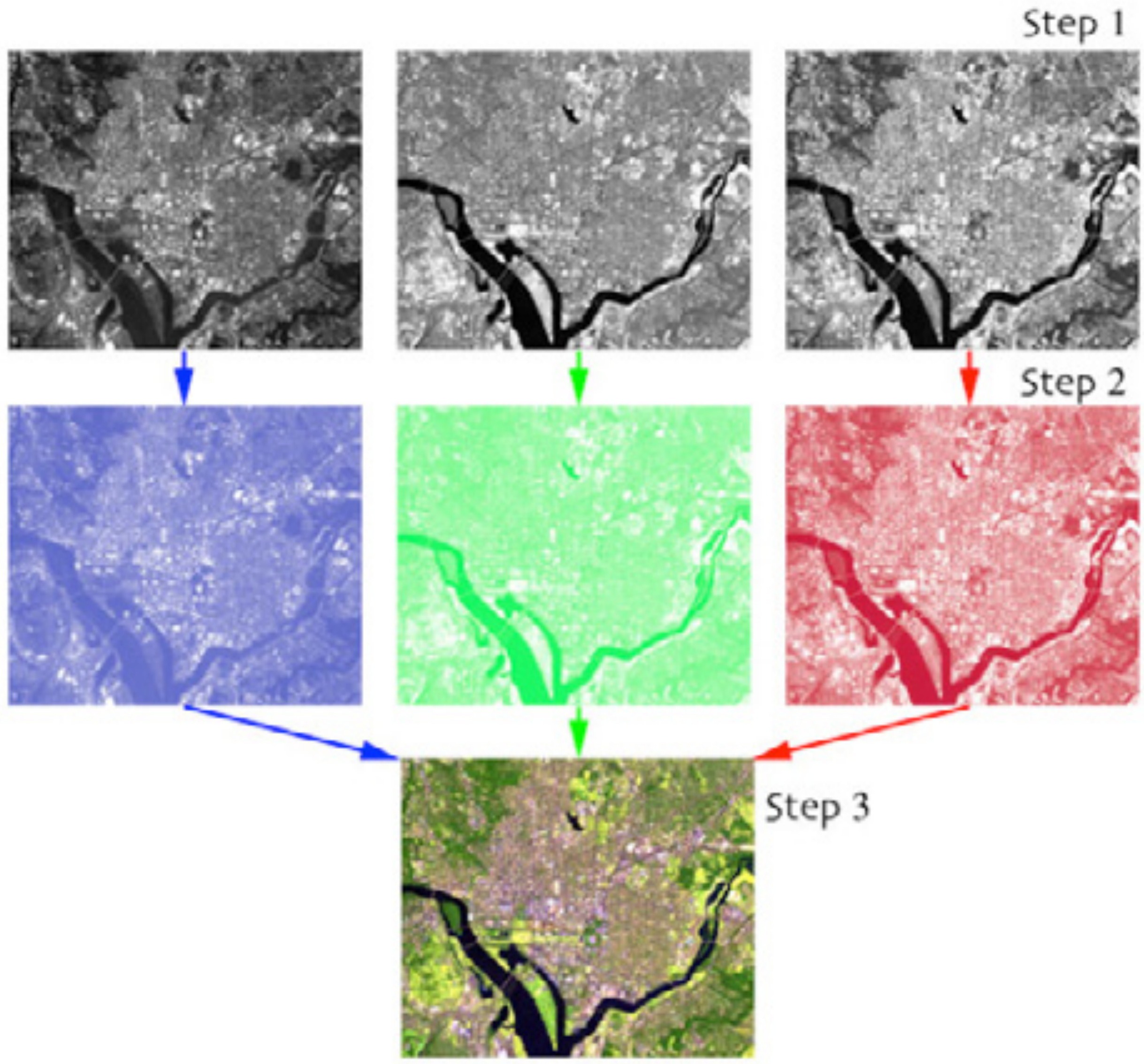
A four-step process takes us from numerical data to a finished image.

Step 1. A sensor onboard Landsat records the values of reflected light in all seven wavelength ranges (bands) on an intensity scale of 0-255.

Step 2. We decide which three of the seven bands we want to use for our image.

Step 3. Using software, we assign a visible color to each of the selected bands.

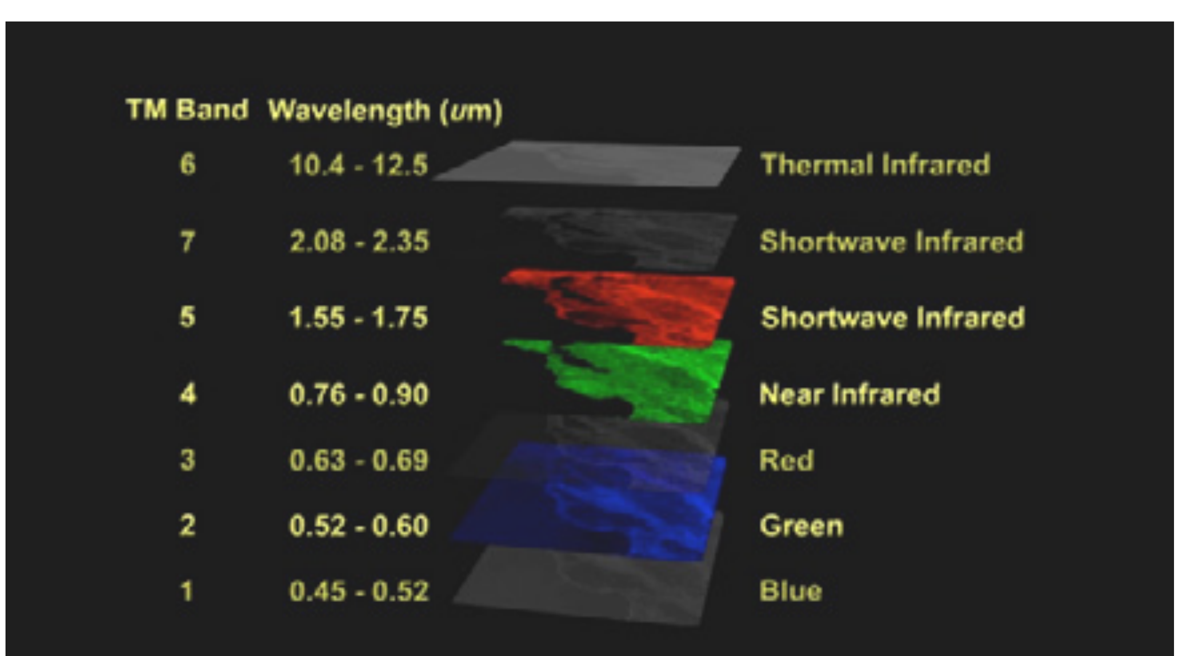
Step 4. We create a composite image from the three bands.



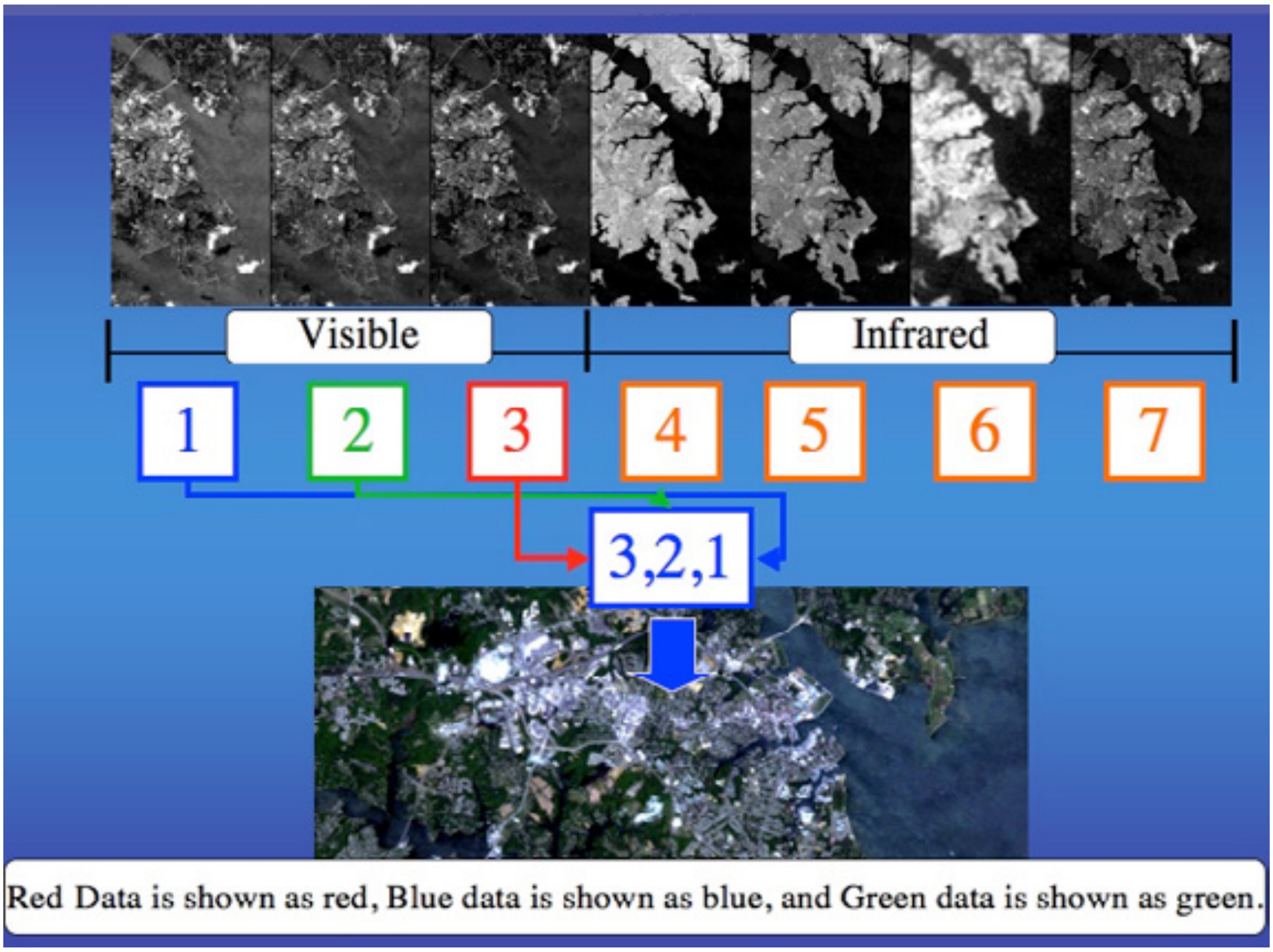
To make the image above, we have chosen to assign

- the color red to represent what is red on the Earth's surface
- the color green to represent what is green on the Earth's surface
- the color blue to represent what is blue on Earth's surface

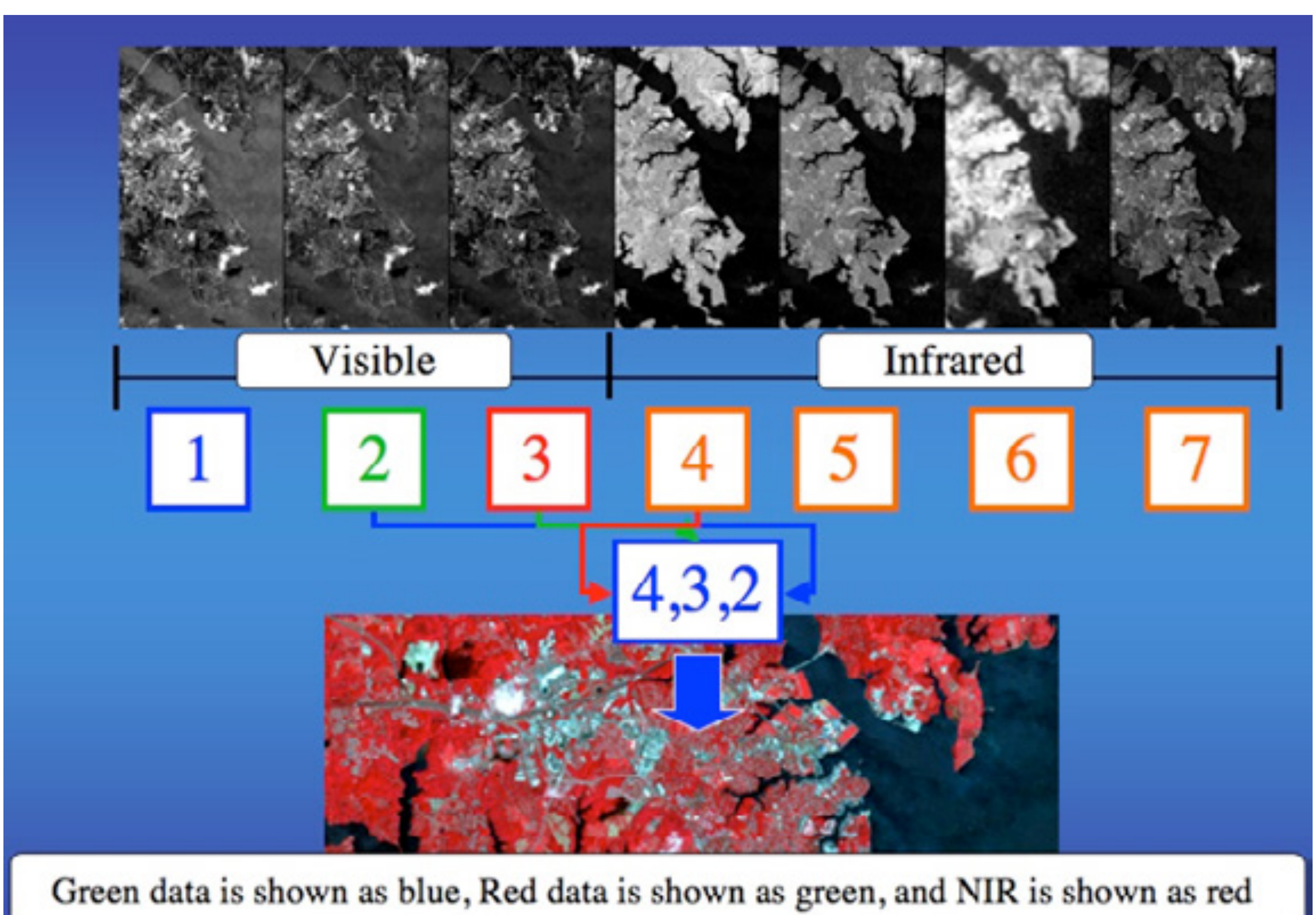
This use of the red, green, and blue bands is as close to true color we can get with the satellite images. The combination of red, green, and blue bands is known as a true color band combination, or a "3,2,1" band combination for the corresponding red (3), green (2), and blue (1).



Below is yet another way of looking at the band combination process for a 3, 2, 1 (true color) band combination.



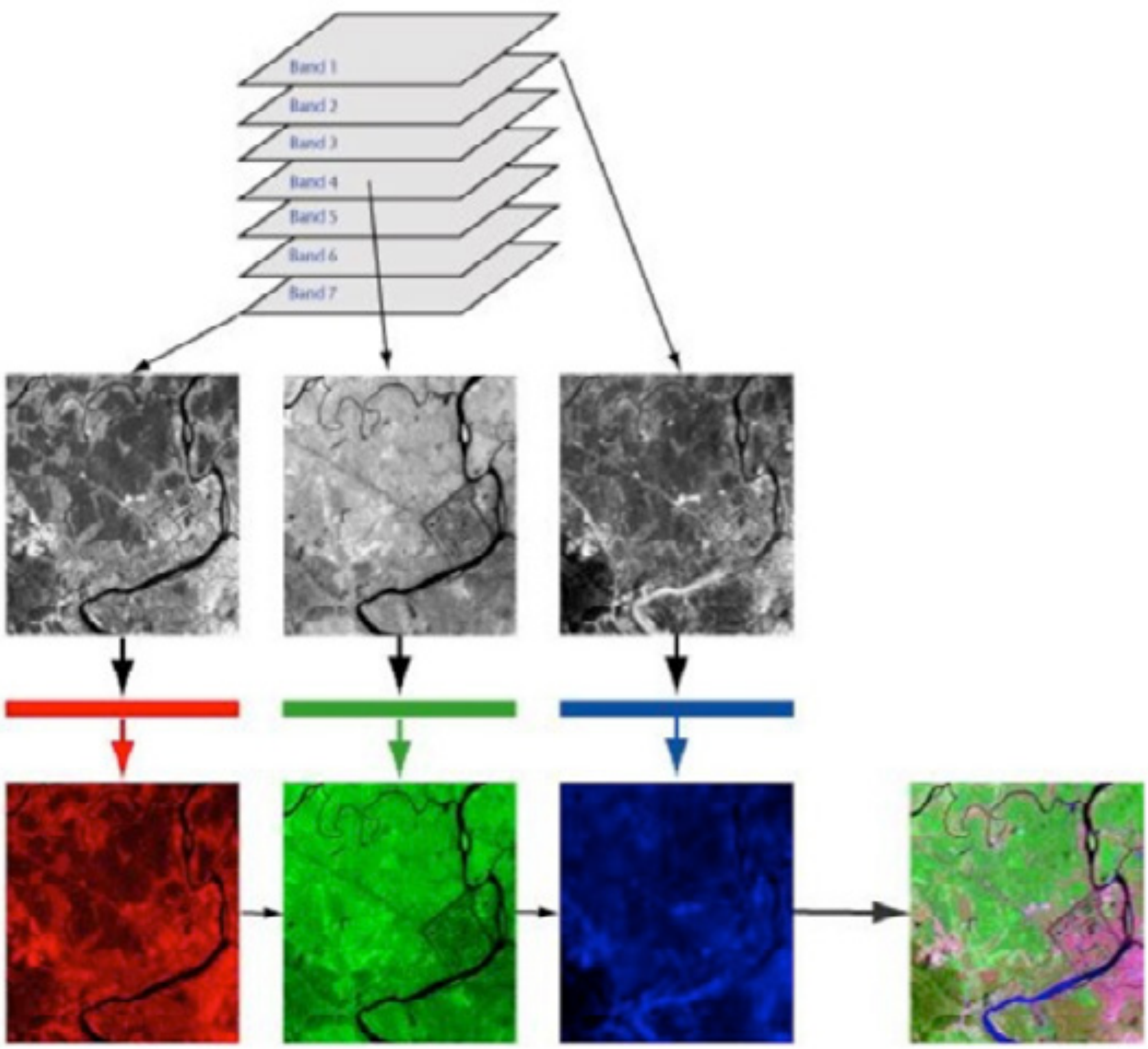
Below is a similar example for the 4, 3, 2 band combination.



It does not matter what wavelengths of light are in the data to begin with; we must see them in shades of red, green, and/or blue. If we choose to use infrared sensors, for example, values of infrared can be converted to values in red, which we can see.

Why use 3,2,1? Why not 1,2,3?
The convention initiated by Landsat engineers and followed forever after by Landsat users is to list the bands according to which of them is to appear red in the image, which is to appear green, and then which is to appear blue. Since the band that detects red wavelengths is Band 3, the band that detects green wavelengths is Band 2, and the band that detects blue wavelengths is Band 1, the band combination of those three is called a 3, 2, 1 combination. It seems backwards, but we have to assume the engineers had a good reason for doing it that way.

Here is another way of looking at the process. It uses Bands 2, 4, and 7.



Creating a color image using three bands from a satellite image. In this example, bands 2, 4, and 7 are used. The grayscale values, as you can see in the upper row, are different for each band, because that location on the Earth reflects more or less strongly in the different wavelengths. In the final composite image, the vegetation (Band 2) is a bright green, cities (Band 4, near infrared) are dark pink, and the river (Band 7, far infrared) is blue. Credit: American Museum of Natural History, Center for Biodiversity and Conservation

Below is a series of images that use different band combinations. Look to see which band combinations are best at showing different features, such as farming fields vs. water or urban areas. Following these images is a section that describes the kinds of information each three-band composite image provides.

3, 2, 1 band combination

4, 5, 3 band combination

7, 4, 2 band combination

7, 5, 3 band combination

You can experiment with choosing band combinations at this URL hosted by the American Museum of Natural History in New York:
http://biodiversityinformatics.amnh.org/tool.php?content_id=141 and
http://biodiversityinformatics.amnh.org/tool.php?content_id=142

True Color and False Color

A true-color image is one that appears close to the colors of the subject as people would see them with our eyes alone. In other words, a red roof appears red in the image, healthy vegetation appears green, and a blue swimming pool appears blue. If we want to make a true color image, we tell the software to use red for the wavelengths that appear red to our eyes; we tell it to use green in the image for the wavelengths that appear green to our eyes; and we tell it to use blue in the image for the wavelengths that appear blue to us. Again that is known as a 3, 2, 1 band combination.

A false color image includes wavelengths we cannot see with our eyes alone, and they are represented by a visible color. We get to chose or assign a color we can see to represent wavelengths that would be otherwise invisible. An example of a false color image would be one in which infrared data appeared as red.

Three Common Band Combinations

True-Color Composite

- Landsat 5 & 7 Bands (3,2,1) Landsat 8 Bands (4,3,2)

True-color composite images approximate the range of vision for the human eye, and hence these images appear to be close to what we would expect to see in a normal photograph. True-color images tend to be low in contrast and somewhat hazy in appearance. This is because blue light is more susceptible than other bandwidths to scattering by the atmosphere. Broad-based analysis of underwater features and landcover are representative applications for true-color composites.

Near Infrared Composite

- Landsat 5 & 7 Bands (4,3,2) Landsat 8 Bands (5,4,3)

Adding a near infrared (NIR) band, and dropping the visible blue band creates a near infrared composite image. Vegetation in the NIR band is highly reflective due to chlorophyll, and an NIR composite vividly shows vegetation in various shades of red. Water appears dark, almost black, due to the absorption of energy in the visible red and NIR bands.

Shortwave Infrared Composite (7,4,3 or 7,4,2)

- Landsat 5 & 7 Bands (7,4,3 or 7,4,2) Landsat 8 Bands (7,5,3)

A shortwave infrared composite image is one that contains at least one shortwave infrared (SWIR) band. Reflectance in the SWIR region is due primarily to moisture content. SWIR bands are especially suited for camouflage detection, change detection, disturbed soils, soil type, and vegetation stress.

Appendix IV. Glossary

-A-

absorption. The process by which electromagnetic radiation (EMR) is assimilated and converted into other forms of energy, primarily heat. Absorption takes place only on the EMR that enters a medium. A substance that absorbs EMR may also be a medium of refraction, diffraction, or scattering; however, these processes involve no energy retention or transformation and are distinct from absorption.

absorption band. A range of wavelengths (or frequencies) of electromagnetic radiation that is assimilated by the atmosphere or other substance.

acquisition. **(1)** Image captured by satellite sensor. **(2)** The process of searching for and locking onto a received signal.

albedo. **(1)** The ratio of the amount of electromagnetic energy reflected by a surface to the amount of energy incident upon it, often expressed as a percentage. **(2)** The reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun, and normal to the incident radiation. Albedo may refer to the entire solar spectrum or merely to the visible portion.

alignment data. Angular measurement of the physical position of the optical axis with respect to the primary space vehicle reference axes.

altitude. Height above a datum, the datum usually being mean sea level. Refers to point above the Earth's surface rather than those on it (elevation).

analog-to-digital conversion. The process of sampling continuous analog signals in order to convert them into a stream of digital values. ETM+ data undergo such a conversion prior to downlinking. Abbreviated as A/D conversion.

angular velocity. Also called rotational velocity, it is the amount of rotation that a spacecraft undergoes per unit time. For Landsat 7 it is equal to 1.059 mrad/sec ((233 paths/cycle * 2*pi*1000 mrad/path) / (16 days/cycle * 86400 sec/day)).

angle of drift. The angle between the heading of the axis of a craft and its ground track. anomaly. A deviation from the norm.

aperture. An opening that admits electromagnetic radiation to a detector or film. An example would be the lens diaphragm opening in a camera.

apogee. The point in the orbit of a heavenly body, especially of a manmade satellite, at which it is farthest from the Earth.

ascending node. The point at which the orbit of an earth satellite intersects the plane of the equator going from south to north.

at-aperture-radiance. The radiance at the aperture of the sensor.

attenuation. The reduction in the intensity of radiation with distance from its source due to atmospheric absorption and/or scattering. It does not include the inverse-square decrease of intensity of radiation with distance from the source.

attitude. The angular orientation of a spacecraft as determined by the relationship between its axes and some reference line or plane or some fixed system of axes. Usually, Y is used for the axis that defines the direction of flight, x for the crosstrack axis, perpendicular to the direction of flight, and z for the vertical axis. Roll is the deviation from the vertical (the angle between the z-axis of the vehicle and the vertical axis, or angular rotation around the y-axis). Pitch is the angular rotation around the x-axis. Yaw is rotation around the z-axis.

azimuth. The arc of the horizon measured clockwise from the north point to the point referenced. Expressed in degrees. Azimuth indicates direction, not location.

-B-

background. Any effect in a sensor or other apparatus or system above which the phenomenon of interest must manifest itself before it can be observed.
band sequential. A format that arranges the data by band such that all of the data from band 1 followed by all of the data from band 2, etc.

band, spectral. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers. With Landsat, bands designate the specific wavelength intervals at which images are acquired.

BCH. An error detection and correction scheme named after its inventors Bose, Chanduri, and Hochergan.

black body. An ideal body which, if it existed, would be a perfect absorber and a perfect radiator, absorbing all incident radiation, reflecting none, and emitting radiation at wavelengths. In remote sensing, the exitance curves of black bodies at various temperatures can be used to model naturally occurring phenomena like solar radiation and terrestrial emmitance.

brightness value. In Landsat parlance, a number in the range of 0-255 that is related to the amount of planetary radiance striking a sensor's detector.

-C-

calibration data. In remote sensing, measurements pertaining to the spectral or geometric characteristics of a sensor or radiation source. Calibration data are obtained through the use of a fixed energy source such as a calibration lamp, a temperature plate, or a geometric test pattern. The application of calibration data to restore measurements to their true values is called rectification.

coherent noise. The noise associated with periodic signals arising from power supplies, transmitters and clock signal typically.

color. That property of an object which is dependent on the wavelength of the light it reflects or, in the case of a luminescent body, the wavelength of the light it emits. If, in either case, this light is of a single wavelength, the color seen is a pure spectral color, but, if the light of two or more wavelengths is emitted, the color will be mixed. White light is a balanced mixture of all the visible spectral colors.

color composite. A color image produced by the combination of three individual monochrome images in which each is assigned a given color. For ETM+ data, if blue is assigned to band 1, green assigned to band 2, and red assigned to band 3, a true color image will result.

cubic convolution. A high-order resampling technique is which the brightness value of a pixel in a corrected image is interpolated from the brightness values of the 16 nearest pixels around the location of the corrected pixel.

-D-

data capture. The receipt and storage of return link mission data at the CADU level.
data continuity. A NASA requirement to ensure that Landsat 7 data are compatible to those obtained by earlier Landsat satellites.

data granule. The increment of image data stored in the archive, i.e. an interval, swath, or WRS scene.

data loads. Data and command transfers from the MOC to the onboard computer.
dark shutter image data. The image data obtained from ETM+ detectors when the calibration shutter obscures the detectors from incident electromagnetic radiation.
descending node. The point at which the orbit of an earth satellite intersects the plane of the equator going from north to south.

detector. The composite circuitry supporting the development of a single output data sample.

detector sample. The process of determining the transfer characteristics (detector mean output as a function of incident exposure) for each detector element.

digital terrain elevation data (DTED). Digital information produced by DMA which provides a uniform matrix of terrain elevation values. DTED is commonly used to terrain correct Landsat data.

distortion. A change in scale from one part of an image to another.
dwell time. Refers to the momentary time interval during which a detector is able to, or allowed to, sense incoming electromagnetic radiation within its intended instantaneous field of view.

dynamic range. The ratio of the maximum signal to the smallest measurable signal.

-E-

EDC. Earth Resources Observation System Data Center is a national archive, production, distribution and research facility for remotely sensed data and other geographic information. (see EROS)

electromagnetic radiation. Energy emitted as result of changes in atomic and molecular energy states and propagated through space at the speed of light.

electromagnetic spectrum. The system that classifies, according to wavelength, all energy (from short cosmic to long radio) that moves, harmonically, at the constant velocity of light.

elevation. Vertical distance from the datum, usually mean sea level, to a point or object on the Earth's surface.

emission. With respect to electromagnetic radiation, the process by which a body emits electromagnetic radiation as a consequence of its kinetic temperature only.

emissivity. Ratio of radiation emitted by a surface to the radiation emitted by a black body at the same temperature under similar conditions. May be expressed as total emissivity (for all wavelengths), spectral emissivity (as a function of wavelength), or goniometric emissivity (as a function of angle).

Enhanced Thematic Mapper Plus (ETM+). The ETM+ is a fixed-position nadir viewing whisk-broom instrument. The viewing swath is produced by means of an oscillating mirror system that sweeps across track as the sensor field of view moves forward along-track due to satellite motion.

ETM+ scene. A set of ETM+ observations that covers 170 km in width by 185 km in length and is centered about a WRS vertex.

engineering data. All data available on-board about health, safety, environment or status of the platform and instruments.

ephemeris. A set of data that provides the assigned places of a celestial body (including a manmade satellite) for regular intervals. Ephemeris data help to characterize the conditions under which remote sensing data are collected and may be used to correct the sensor data prior to analysis.

EROS. The Earth Resources Observation System was established in the early 1970?s under the Department of Interior? U.S. Geological Survey, to receive, process and distribute data from the United States? Landsat satellite sensors and from airborne mapping cameras.

-F-

field-of-view. The solid angle through which an instrument is sensitive to radiation. See effective resolution element, instantaneous field of view, resolution.

focal length. In a camera, the distance measured along the optical axis from the optical center of the lens to the plane at which the image of a very distant object is brought into focus.

focal plane. In a sensor, the plane occupied by the detectors, and on which the radiances sensed are incident.

frame. For Landsat 7, a frame is one Virtual Channel Data Unit with a frame synchronizer pattern (frame marker) attached. This is the same as a Channel Access Data Unit (CADU).

-G-

geocentric. Any coordinate frame whose origin is relative to the Earth's center of mass.

geometric correction. The transformation of image data, such as Landsat data, to match spatial relationships as they are on the Earth. Includes correction for band-to-band offsets, line length, Earth rotation, and detector-to-detector sampling delay. For ETM+ data, a distinction is made between data that have been geometrically corrected using systematic, or predicted, values and data that have been geometrically corrected using precise ground control point data and elevations models.

geodetic coordinates. Quantities which define the position of a point on the spheroid of reference (for example, the Earth) with respect to the planes of the geodetic equator and of a reference meridian. Commonly expressed in terms of latitude and longitude.
geodetic accuracy. A measure of how closely a point on the Earth can be located relative to its true absolute location.

geosynchronous. An Earth satellite orbit in which the satellite remains in a fixed position over a geographic location on Earth.

Global Position System (GPS). A constellation of satellites that can be used to determine accurately the orbit data of satellites.

ground control point (GCP). A geographic feature of known location that is recognizable on images and can be used to determine geometric correction functions for those images.

ground track. The vertical projection of the actual flight path of a plane or space vehicle onto the surface of the Earth.

ground truth. Data which are acquired from field checks, high-resolution remote sensing data, or other sources of known data. Ground truth is used as the basis for making decisions on training areas and evaluating classification results.

-G-

housekeeping data. All data available onboard about health, safety, environment, or status of the platform and instruments.

hue. The attribute of a color that differentiates it from gray of the same brilliance and that allows it to be classed as blue, green, red, or intermediate shades of these colors.

-I-

image. The recorded representation of an object produced by optical, electro-optical, optical-mechanical, or electronic means. It is the term generally used when the electromagnetic radiation emitted or reflected from a scene is not directly recorded on photographic film.

image enhancement. Any one of a group of operations which improves the interpretability of an image or the detectability of targets or categories in the image. These operations include contrast enhancement, edge enhancement, spatial filtering, image smoothing, and image sharpening.

image restoration. A process by which a degraded image is restored to its original condition. Image restoration is possible only to the extent that the degradation transform is mathematically invertable.

irradiance. The measure, in units of power, of radiant flux incident on a surface.

-J-

jitter. Small rapid variations in a variable (such as a waveform) due to deliberate or accidental electrical or mechanical disturbances or to changes in the supply of voltages, in the characteristics of components. Jitter effects arising from the oscillating mirrors and other movable parts aboard the Landsat spacecraft are often a cause of certain anomalies in the image data received and must be compensated for by the ground processing software.

-K-

K-band. A radio frequency band extending from approximately 12.5 to 36 gigahertz.

kernel. In the spatial domain, a kernel is a MxM operator which can be used in the convolution or multiplication with a NxN image to accentuate certain features or properties of an image. A kernel can also be represented in the frequency domain as a Fourier transform.

-L-

L-band. A radio frequency band extending from approximately 1.0 to 2.0 gigahertz.
Landsat 7. Consists of the spacecraft and the ETM+ payload.

level 0. Space vehicle or instrument data at full space-time resolution with space-to-ground communication artifacts removed.

light, transmitted. Light that has traveled through a medium without being absorbed or scattered.

long term acquisition plan. The tasking of the sensor using cloud predictions to optimize the acquisition of cloud free scenes.

lookup table. An array of values from which functions corresponding to a given argument can be obtained.

-M-

major frame. For ETM+, a major frame period is one complete scan of the ETM+ scan mirror (either direction), which includes not only the period during a scan but also the turnaround interval when the scan mirror changes direction for the next scan.

map projection. Any systematic arrangement of meridians and parallels portraying the curved surface of a sphere or spheroid upon a plane.

metadata. An archived set of descriptive information about a scene and the parent sub-interval that provides a user with geographic coverage, date of acquisition, sun angles, could cover, gain states, and other quality measurements.

minor frame. For ETM+ major frames are partitioned into minor frames which is the most fundamental element of the data stream structure in which specific data measurands (e.g. imagery, PCD, time codes) are extracted.

mirror scan correction data. This data includes scan start time, first half scan time error, second half scan time error, scan direction, and any other data which is required to perform mirror scan correction.

modulate. To vary, or control, the frequency, phase, or amplitude of an electromagnetic wave or other variable.

modulation transfer function (MTF). The modulation transfer function of an imaging system measures the spatial frequency modulation response of the system. As an imaging system processes or records an image, the contrast modulation of the processed or recorded image is different from the input image. The MTF can be thought of as a curve, indicating for each spatial frequency the ratio of the contrast modulation of the output image to the contrast modulation of the input image. It is formally defined as the magnitude of the Fourier transform of the line spread function of the imaging system. mosaic. An image made by piecing together individual images covering adjacent areas.

multiplexer. An electronic device which permits the transmission of multiple messages simultaneously on one communication channel.

multispectral. Generally denotes remote sensing in two or more spectral bands, such as visible and infrared.

-N-

nadir. That point on the celestial sphere vertically below the observer, or 180° from the zenith.

narrowband data. The data includes the command or forward ranging in the narrowband forward link, and the telemetry or return ranging in the narrowband return link.

near infrared. The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 µm (visible red) to about 3 µm. The longer wavelength end grades into the middle infrared. Sometimes called solar infrared, as it is only available for use during the daylight hours. Also known as the shortwave infrared (SWIR).

node. Either of the two points at which the orbit of a heavenly body intersects a given plane, especially the plane of ecliptic. With respect to Landsat, the orbital nodes occur at the equator, one on the descending, or daylight, track of the orbit and the other on the ascending, or nighttime, track.

noise. Any unwanted disturbance affecting a measurement (as of a frequency band), especially that which degrades the information-bearing quality of the data of interest.

Nyquist interval. The maximum time interval between equally spaced samples of a signal that will enable the signal waveform to be completely determined. The Nyquist interval is equal to the reciprocal of twice the highest frequency component of the sampled signal.

Nyquist's theorem: A theorem, developed by H. Nyquist, which states that an analog signal waveform may be uniquely reconstructed, without error, from samples taken at equal time intervals. The sampling rate must be equal to, or greater than, twice the highest frequency component in the analog signal.

-O-

optical transfer function (OTF). A mathematical statement that describes the relationship between the input and the output of an imaging system. When the transfer function operates on the input, the output is obtained. Given any two of these three entities, the third can be obtained.

orbit adjust. The adding to or taking away of orbital velocity. This is normally done to maintain altitude or orbit phasing relationships.

orbital period. The interval in time between successive passages (orbits) of a satellite through a reference plane.

orthorectified. Describing an image in which terrain relief distortions have been removed.

-P-

panchromatic. A single band covering a broad range of wavelengths; usually used in context of collecting information from the whole visible spectrum.

parallax. The apparent change in the position of one object, or point, with respect to another, when viewed from different angles.

path. The longitudinal center line of a Landsat scene of a Landsat scene, corresponding to the center of an orbital track. Sequential numbers from east to west are assigned to 233 nominal satellite tracks for Landsat 7. Path numbers are used with row numbers to designate nominal scene center points.

payload. That part of a spacecraft (e.g. ETM+) that is separate from the equipment or operations necessary to maintain the spacecraft in orbit.

payload correction data. Image support data imbedded in the wideband data stream. Includes satellite attitude, ephemeris, time, angular displacement sensor (ADS) data and payload state.

perigee. The point in the orbit of a heavenly body (e.g. satellite) at which it is nearest the Earth.

pixel. Picture element provided by a single detector scene sample output.

pitch. The rotation of a spacecraft about the horizontal axis normal to its longitudinal axis (in the along-track direction) so as to cause a nose-up or nose-down attitude.

polar stereographic. An azimuthal stereographic projection commonly used with Landsat data acquired about 65° latitude. In this projection, the meridians are straight lines converging at the pole (central point), and lines of latitude are concentric circles about this point. Like the UTM projection, the polar stereographic is a conformal projection, meaning that angular relationships are preserved.

pole wander. The apparent motion in the poles of the Earth relative to inertial coordinate system. Changes in moments of inertia are due to changes in moments of density due primarily to tides and liquid mass. The National Imager and Mapping Agency (NIMA) generates pole wander data which are used by the Landsat 7 system in the conversion of downlinked ephemeris from inertial to fixed reference, during Level 0R processing.

precision correction. Post-processed geometric correction of satellite data using ground control points to correlate the spacecraft's predicted position with its actual geodetic position.

prime meridian. Meridian of longitude 0 degrees, used as the origin for measurements of longitude. The meridian of Greenwich, England, is the internationally accepted prime meridian on most charts.

-Q-

quantization level. The number of numerical values used to represent a continuous quantity.

quaternion. A vector of four components; the position is contained in the first three components and an associated scalar rater is located in the last component of this four element vector.

-R-

radian. The angle subtended by an arc of a circle equal in length to the radius of the circle: 57.3°

radiance. Measure of the energy radiated by an object. In general, radiance is a function of viewing angle and spectral wavelength and is expressed as energy per solid angle.

Rayleigh scattering. Selective scattering of light in the atmosphere by particles that are small compared with the wavelength of light.

reflectance. The ratio of the radiant energy reflected by a body to that incident upon it. In general, reflectance is a function of the incident angle of the energy, viewing angle of the sensor, spectral wavelength and bandwidth, and the nature of the object.

registration. The process of geometrically aligning two or more sets of image data such that resolution cells for a common ground area can be digitally or visually superimposed. roll. The rotation of a spacecraft about its longitudinal axis (in the along-track direction) so as to cause a side-up or side-down attitude. The roll axis is referred to as the y axis.

row. The latitudinal (nominal) center line of a Landsat scene. Row 1 is at latitude 80° 47'N, row 60 is at the equator, and row 122 is at latitude 81° 51'S. In total there are 248 rows.

-S-

sampling rate. The number of samples taken per unit time, i.e., the rate at which signals are sampled for subsequent use, such as for modulation, coding, and quantization.

saturation. The condition where energy flux exceeds the sensitivity range of a detector.

S band. A radio frequency band extending from approximately 2.0 to 4.0 gigahertz.

sidelap. The extent of lateral overlap between images acquired over adjacent ground tracks.

signal-to-noise ratio. The ratio of the level of the information-bearing signal power to the level of the noise power. More precisely, the signal-to-noise ratio of the mean DN to the standard deviation in DN. This is a temporal noise definition in that the mean DN is the time averaged value and the standard deviation in DN is the standard deviation in the time series.

space oblique mercator. A variation on the basic mercator map projection based on the dynamics of satellite motion. The movements of the satellite, sensor, and the Earth, expressed as functions of time, are used to calculate which latitudes and longitudes on the Earth correspond to locations in the projection plane.

spectral band. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

spectral response. The response of a material as a function of wavelength to incident electromagnetic energy, particularly in terms of the measurable energy reflected from and emitted by the material.

spectral signature. The quantitative measurement of the properties of an object at one or several wavelength intervals. Spectral signature analysis techniques use the variation in the spectral reflectance or emittance of objects as a method of identifying the objects.

steradian. A unit of measure of solid angles. Formally, it is the angle subtended at the center of the sphere by a portion of the surface whose area is equal to the square of the radius of the sphere. There are 4 pi steradians in a sphere.

subinterval. Is a contiguous segment of raw wideband data received during a Landsat 7 contact period. Subintervals are caused by breaks in the wideband datastream due to communication dropouts and/or the inability of the spacecraft to transmit a complete observation (interval) within a single Landsat 7 contact period. The largest possible subinterval is 35 full scenes long with a partial scene preamble and postamble. The smallest possible subinterval is a single ETM+ scene.

sun elevation angle. The angle of the Sun above the horizon.

solar zenith angle. Reciprocal of the sun elevation angle.

sun synchronous. An Earth satellite orbit in which the orbital plane remains at a fixed angle with respect to the Sun, precessing through 360° during the period of a year. swath. Refers to the 185 kilometer wide ETM+ imaging ground track.

swath. Refers to the 185 kilometer wide ETM+ imaging ground track.

-T-

telemetry. The science of measuring a quantity, transmitting the measured value to a distant station, and there, interpreting or recording the quantity measured.

temporal. Pertaining to, concerned with, or limited by time.

temporal resolution. The expected repeat time between measurements over the same location.

thermal band. A general term for intermediate and long wavelength infrared-emitted radiation, as contrasted to short wavelength reflected infrared radiation. In practice, generally refers to infrared radiation emitted in the 3-5 µm and 9-14 µm atmospheric windows.

thermal infrared. The preferred term for the middle wavelength ranges of the infrared region extending roughly from 3 µm at the end of the near infrared, to about 15 or 20 m where the far infrared commences. In practice the limits represent the the envelope of energy emitted by the Earth behaving as a graybody with a surface temperature around 290 K. Seen from space, the radiance envelope has several brighter bands corresponding to windows in the atmospheric absorption bands. The thermal band most used in remote sensing extends from 8 to 15 µm.

time, Greenwich mean. Mean solar time of the meridian of Greenwich, England (longitude 0), used by most navigators and adopted as the prime basis of standard time throughout the world. Abbreviated GMT.

time, mean Sun. The mean Sun time at a given location on the Earth is determined by the distance in longitude from the Greenwich meridian. The mean Sun time at any location is determined by dividing the difference in longitude from Greenwich (in degrees, moving east) by 15 and adding the result to the current GMT. This will be mean Sun time relative to Greenwich, expressed in hours.

transmittance. The ratio of the energy per unit time per unit area (radiant power density) transmitted through an object to the energy per unit time per unit area incident on the object. In general, transmittance is a function of the incident angle of the energy, viewing angle of the sensor, spectral wavelength and bandwidth, and the nature of the object.

-U-

ultraviolet radiation. Electromagnetic radiation of shorter wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4,000 angstroms.

umbra. The complete or perfect shadow of an opaque body, as a planet, where the light from the source of illumination is completely cut off.

universal transverse mercator. A widely used map projection employing a series of identical projections around the world in the intermediate latitudes, each covering 6 degrees of longitude and oriented to a meridian. The UTM projection is characterized by its property of conformality, meaning that it preserves scale and angular relationships well, and by the ease with which it allows a useful rectangular grid to be superimposed on it. The UTM projection is most commonly used with landsat data.

UT1-UTC time correction data. Universal Time (UT) 1 is determined from observations of stellar transits to determine local mean sidereal time corrected to remove the effects of polar motion. Universal Time Coordinated (UTC) is defined to be equal to that of the International System used for atomic time, but it is kept with .9 seconds of UT1 by periodic leap-second adjustments.

-V-

virtual channel data unit (VCDU). The CCSDS protocol data unit consisting of a fixed length data structure. It is used for bidirectionally space/ground communications on a CCSDS virtual channel.

visible radiation. Electromagnetic radiation of the wavelength interval to which the human eye is sensitive; the spectral interval from approximately 0.4 to 0.7 µm.

-W-

wavelength. Wavelength = 1/frequency. In general, the mean distance between maximums (or minimums) of roughly periodic pattern. Specifically, the shortest distance between particles moving in the same phase of oscillation in a wave disturbance.

world geodetic system (WGS). The reference Earth model used by the Landsat 7 system. worldwide reference system. A global indexing system for Landsat data which is based on nominal scene centers defined by path and row coordinates.

-X-

X-band. A radio frequency band extending from approximately 8.0 to 12.5 gigahertz.

-Y-

yaw. The rotation of a spacecraft about its vertical axis so as to cause the spacecraft's longitudinal axis to deviate left or right from the direction of flight. The yaw axis is referred to as the z axis.

-Z-

zenith. The point in the celestial sphere that is exactly overhead.